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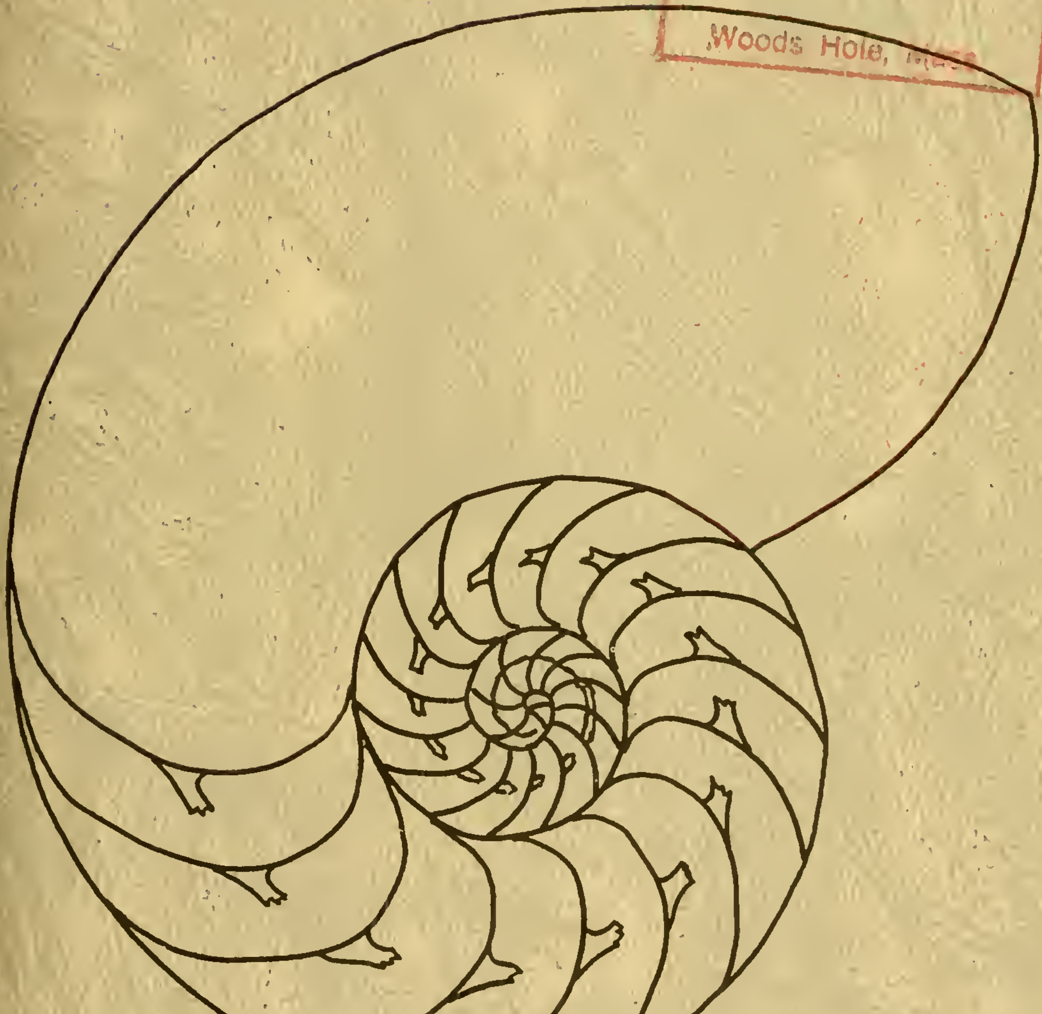

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ERRATUM: The running heads at the top of the page in the last, October 1979, issue should have read Vol. 93 not 94. Further, the species names in the table of contents should not have been capitalized. The printer and editor apologize.

CONTENTS

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I certify that the statements made by me above are correct and complete.
(signed) R. Tucker Abbott, Editor

SHORT PAPERS

PLEUROPLOCA AURANTIACA (LAMARCK) (FASCIOLARIIDAE) IN THE GRENADINES, LESSER ANTILLES

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The Caribbean molluscan faunal province extends south to Brazil, (Abbott, 1968). However, no specimen of *Pleuroploca aurantiaca* has been reported in the Caribbean Sea area. In fact, the species is considered to be endemic to Brazil, with its range extending from Espirito Santo to Amapa, Brazil, (Rios, 1975).

Recently, two live specimens were collected by Mr. James Whitney and myself, in Carriacou, an island 32 km north of Grenada, (3,000 km from Amapa), one at Windward Reef, January, 1978, and the other at the Sunset Beach area, March, 1978, at depths of approximately 13 m. On further inquiry, it was learned that other specimens have also been found in Grenada at Westerhall Bay and Calivigny Island, Grenada (D. L. N. Vink and D. Willcox, *personal communications*). This species has not, as yet, been reported from the Trinidad/Tobago region, the chain of islands connecting South America and the Grenadines.

FIG. 1. Pleuroploca aurantiaca *(Lamarck) from Windward Reef, Carriacou, collected by Mr. J. Whitney at 13 m depth on January 1978; and photographed by Mr. K. Pitcher. 150 mm.*

Both Carriacou Island shells were adult specimens, measuring approximately 150 mm in length. The shell resembles *Pleuroploca gigantea* (Kiener) in outline, but has a more prominent shoulder and numerous spiral cords bearing heavy beads. The most distinguishing feature is the color of the live soft parts, which are not red, as in *P. gigantea*, but are light-tan with numerous rectangular markings of bright torquoise-blue.

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RANGIA CUNEATA IN AN INDUSTRIAL WATER SYSTEM (BIVALVIA: MACTRIDAE)

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Rangia cuneata (Sowerby, 1831) is commonly found in fresh and brackish coastal waters from Chesapeake Bay to Texas (Abbott, 1974). The northernmost extension of its range has been reported as the upper reaches of the Chesapeake Bay where severe winter temperatures have caused mass mortalities (Gallagher and Wells, 1969). The present report records for the first time the presence of *R. cuneata* in Delaware Bay.

Adult specimens of this clam were collected from the water system of the Getty Oil Refinery, Delaware City, New Castle County, Delaware,

during May 1979. The clams were discovered by employees during a minor fire when nozzle pressure of the fire hoses was significantly reduced. When the nozzle was removed, adult *R. cuneata* fell from the fire hose.

The source of the water for the refinery's water system is the Delaware River. Water is pumped through a 40.64 cm screened intake pipe and then pumped to a 3,103,700 liter tank which serves as a reservoir for the fire and cooling systems. Pipes in these systems range from 7.62 cm to 40.64 cm in diameter. The water in the pipes is usually treated three times a day by slow feed (25 min) hypochlorination which leaves a residual free chlorine level of less than 3 ppm in the water. Invasion of the system was attributed to a breakdown of the chlorination system during the late spring of 1978. It thus appears that *R. cuneata* has tolerated this concentration of chlorine, although no data is available to indicate its effects on the survival of larvae in the water system.

The appearance of *R. cuneata* in Delaware Bay may have resulted from clams migrating through the Chesapeake-Delaware Canal which connects northern Chesapeake Bay with Delaware River upstream of the oil refinery. The present paper is also the first to report *R. cuneata* as a biofouling nuisance. The circumstances in which *R. cuneata* were collected is a striking parallel to problems usually associated with *Corbicula* (Ingram, 1956; Sinclair, 1971).

The author wishes to thank Dr. R. Tucker Abbott for confirming the identification of the species and Dr. Melbourne R. Carriker for his review of the manuscript. University of Delaware, College of Marine Studies Contribution No. 142.

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FOSSIL *RANGIA CUNEATA* (MACTRIDAE) IN EDDY COUNTY, NEW MEXICO

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Presence of fossils of the brackish water, mactrid clam *Rangia cuneata* (Sowerby, 1831), in southeastern New Mexico was noted by Andrews (1977:220). Herein, more specific information concerning these occurrences is provided.

Shells (Figs. 1, 2) have been taken at three localities (listed below) along the Pecos River, east of Malaga, Eddy County. At none of these places were shells found *in situ* in sediments; however, it seems most likely that they were derived from gravel deposits of Pleistocene age. At Localities 2 and 3 shells were found where quarrying operations had been carried out in gravels of stream-flanking terraces. These gravels are clearly older than inset, Holocene sediments (predominantly silts) and seem likely to be of Pleistocene age. At Locality 1 shells were found in gravels of various sources and ages (Holocene and Pleistocene) along the floodplain of the Pecos River.

Most shells have a limonitic-stained rind of calcium carbonate, especially on their inner surface (Fig. 2) and all are judged to be fossil. No fresh shells have been found here or elsewhere along the Pecos River. Shells collected range from 31 to 42 mm in length.

Occurrence of this estuarine clam so far inland

FIGS. 1-2. *Fossil* Rangia cuneata *(Sowerby) from Locality 1 (see text), Eddy County, New Mexico.*

is unexpected. The nearest populations are on the Texas coast some 800 km to the southeast. There, Andrews (1977:220) noted that *R. cuneata* is a brackish water species that has been found a few miles up the Nueces River. Hopkins *et al* (1973:220) found that *R. cuneata* is usually restricted to estuarine environments because of (1) larval requirements of salinities between 2 and 10 ppt and (2) necessity for salinity changes as a stimulus to induce spawning.

In the area of Malaga Bend (of the Pecos River) where these specimens were taken, numerous springs and seeps contribute a salty brine to the Pecos River. The brine is produced in Upper Permian (Ochoan) strata at the base of the Rustler Formation where its waters contact and dissolve salts of the underlying Salado Formation. Artesian pressure brings the brine upward in the Malaga Bend area (Robinson and Lang, 1938:86-90). In one study (McClure, 1938:75) it was found that there was, in river waters in the 12 km between Malaga and Pierce Crossing gauging stations, an increment of total dissolved solids of "about 420 tons per day of which about eighty percent or 340 tons was common salt."

Although conditions of salinity were seemingly not inimical to *R. cuneata* in this short segment of the Pecos River, the question of how it could have dispersed so far inland is difficult to answer. Movement upstream through the fresh waters of the Rio Grande and lower Pecos River seems unlikely and the area has been far from the sea throughout Tertiary time. Transport by waterfowl seems the most plausible hypothesis to account for this occurrence. An avian transport hypothesis has been advocated by Bachhuber (1977:263-265) to account for presence of foraminifera in Quaternary deposits of Pluvial Lake Estancia in central New Mexico. There are other reports of organisms with marine or brackish water affinities occurring far inland in this region. These include several species of gastropods, occurring as fossils, found by Dr. Dwight W. Taylor farther downstream in the Pecos River drainage in Terrell County, Texas (Andrews, 1977:92, 98, 180). Creel (1964:236-240) reported the extraordinary occurrence of a marine, grapsoid crab and "a barnacle" in salt springs at Estelline, Hall County, Texas, in the Red River drainage.

LOCALITIES OF COLLECTIONS

All localities are along the Pecos River, Eddy County, New Mexico.

1. 32°12′37″N; 104°01′42″W. SE corner, Sec. 13, T. 28 S, R. 29 E. 3.7 km E and 1.6 km S of Malaga. (4 shells).
2. 32°13′05″N; 104°00′05″W. SE¼, SE¼, NE¼, Sec. 17, T. 24 S, R. 29 E. 6.5 km E and 0.9 km S of Malaga, immediately downstream from Fishing Rock (an island in river). (5 shells).
3. 32°11′20″N; 103°58′37″W. SE¼, SW¼, NW¼, Sec. 27, T. 24 S, R. 29 E. On SE side of Pecos River at Pierce Canyon crossing. (3 shells).

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THE INTRODUCTION OF THE LAND SNAIL *ALCADIA STRIATA* (LAMARCK) INTO MIAMI, FLORIDA

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A Puerto Rican snail, *Alcadia striata* Lamarck (Prosobranchia, Helicinidae) has been introduced in Miami, Florida, where at least one breeding population is established. The species was discovered at the Sunlan Aquatic Nursery, 8301 NW 8 St. by plant inspectors from the Florida State Division of Plant Industry (FSDPI). It is abundant on the nursery grounds and on immediately adjacent properties. By now it probably has been introduced, via nursery stock, into other places within the greater Miami area. The nursery has imported ornamental plants from Puerto Rico for about 22 years, from where the snail probably was introduced on nursery stock.

We wish to thank Curtis F. Dowling and Lionel Stange (FSDPI) for bringing to our attention this introduction. Voucher specimens are deposited in the Florida State Museum (UF 25239, 25240).

ANODONTA IMBECILLIS SAY (BIVALVIA: UNIONIDAE) IN THE DELAWARE RIVER BASIN

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Anodonta imbecillis Say is among the geographically more widely distributed of Nearctic naiades, but in the Atlantic drainage it has understandably been considered only a southern species: in a recent comprehensive account, for example, Johnson (1970, *Bulletin of the Museum of Comparative Zoology,* 140:362-364) recorded this species from no farther north in that drainage than the Gunpowder River basin in Maryland. However, we recently (5 June 1976, 5 June 1977) secured numerous *A. imbecillis* in Pickering Creek of the Delaware River basin in Chester County, Pennsylvania.

This unexpected extension of geographic range raises the question of the antecedents of these animals. Do they represent an overlooked natural population or an inadvertent introduction by man? We infer the success of the Pickering Creek population from our having observed gravid females and several age-classes (i.e., reproduction and recruitment). Had there been natural successful populations in the Philadelphia, Pennsylvania, area, the assiduous local investigators of the last 150 years (e.g., William D. Hartman and Isaac Lea) would probably have found them. Consequently, we suspect that the Pickering Creek population was inaugurated by man, but have not as yet gained the necessary information (if extant) regarding the presumed age of the population and the time(s) of introduction(s) of host fishes suitable for larval parasitism by *Anodonta imbecillis*. Further investigation of this and other points of interest concerning this population is underway, and the results will be reported.

Constructive criticism of an early version of this note was offered by Robert C. Bullock of the University of Rhode Island at Kingston.

SOMATOGYRUS (GASTROPODA: HYDROBIIDAE) IN LAKE WINNIPEG, CANADA

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The genus *Somatogyrus* consists of numerous species whose distributional focus lies in the southeastern United States. Some species have spread within the Mississippi River drainage, and a single species, *S. subglobosus* (Say), occurs as far north as the Great Lakes, and the St. Lawrence and Ottawa Rivers (La Rocque, 1968). Neither living nor fossil material of this genus has been reported from areas west or north of the Great Lakes.

Specimens of a *Somatogyrus* species (Fig. 1) were collected at Victoria Beach, on the southeast shore of Lake Winnipeg (50°44′N, 96°36′W) in September of both 1976 and 1978. Although the shells were empty, their relatively fresh condition suggested the existence of a living population offshore. The area is characterized by a sand bottom

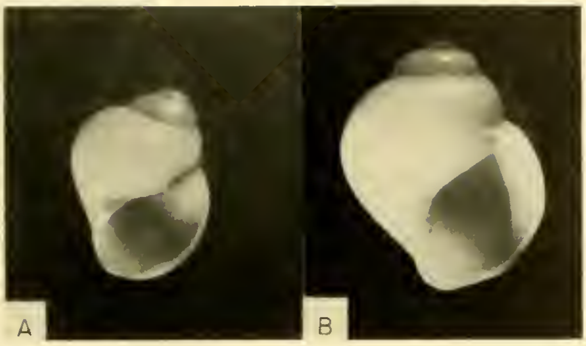

FIG. 1. Somatogyrus *sp. from Lake Winnipeg.* A, *7.3 mm.* B, *6.0 mm.*

strewn with large rocks exposed to heavy wave action and contains submerged stands of *Potamogeton richardsonii, P. pectinatus* and *Myriophyllum exalbescens,* which are populated by a variety of other amnicolids, as well as *Campeloma decisum* Say and by pulmonates. The water chemistry at this site averaged a total filtrable residue value of less than 150 mg/l, a total alkalinity value of less than 100 mg/l $CaCO_3$, and chloride, nitrogen and phosphorus levels of less than 5 mg/l respectively, although sulphate values were as high as 30 mg/l.

The origin of this taxon in Lake Winnipeg is problematic. The Great Lakes system was confluent with Lake Agassiz during Pleistocene times, and the former is at present connected with the Winnipeg River-Rainy River system at Saganaga Lake (48°15'N, 90°55'W) (Clarke, 1973). However surveys by Clarke (1973) and Pip (1978) failed to find *Somatogyrus* in the waters of the Winnipeg and Rainy River system. The record nearest to Lake Winnipeg (Pip, 1978) is based on a specimen from Itasca Co., Minnesota, in the Mississippi River drainage system. Furthermore, the Lake Winnipeg species is not the lirate-apexed *S. subglobosus,* but has a punctate apex and appears to be more closely related to *S. integer* (Say) which is known from the region south of the Great Lakes, and to *S. depressus* (Tryon) from Wisconsin.

Whether the Lake Winnipeg population is indigenous or the result of recent accidental introduction, its apparent establishment presents a substantial range extension for the genus in North America.

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DISCOVERY OF A NEW POPULATION OF *PEGIAS FABULA* (LEA) (UNIONIDAE)

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Simpson (1914) lists the distribution of *Pegias fabula* (Lea, 1838) as the Tennessee and Cumberland River drainages. It appears to be restricted to small, high-gradient tributaries of these drainages (Ortmann, 1918). Stansbery (1976) has proposed *Pegias* for endangered status and has indicated that a few additional previously unknown populations may be discovered in smaller tributaries.

On October 22, 1977, five gravid females of *Pegias fabula* were collected by the authors at Freedom Church Ford on the Little South Fork Cumberland River approximately 8 km north of Ky 92 crossing, Wayne County, Kentucky [Ohio State University Museum (OSUM) 41308 (3), W. C. Starnes CU/BS-2 (2)]. The individuals collected were of rather uniform size ranging from 24.1 mm to 26.7 mm in length and 14.3 mm to 16.7 mm in height. In addition to these live individuals, numerous valves were also collected indicating a substantial population. Additional specimens of similar dimensions were collected by A. and C. Bogan (University of Tennessee) at the same locality on October 30, 1977 [OSUM 41309 (6)].

The Little South Fork Cumberland River at Freedom Church Ford is approximately 20-25 m wide. Except for its clear, cold water, it does not assume headwater characteristics described as typical habitat for *Pegias*. While riffles are present in the area where *Pegias* was collected, there are extensive reaches of pool areas. All *Pegias* specimens were collected from the transition zone at the tail of a long sluggish pool just at the point where water velocity suddenly increased (about 0.2 m/sec) to enter a turbulent riffle below. Water depth averages about 20 cm at low river stages. Substrate was predominately dark sand with scattered small gravel. *Pegias* occurred either partly buried or on the substrate with only the foot penetrating the sand. The periostracum of all individuals had been largely eliminated, apparently from the abrasive action of sand in the current-swept habitat. Similar massive erosion was noted on all specimens examined from several other localities (University Michigan Museum of Zoology, 70152, 23144, 23151, 58872, 105467, 29085, 105469 through 105477). In close association with *Pegias* were *Ptychobranchus subtentum* and *Corbicula manilensis*. Occurring elsewhere in the riffle were *Ptychobranchus fasciolare, Elliptio dilatatus, Medionidus conradicus, Villosa iris, V. taeniata, V. vanuxemi, Lampsilis fasciola,* and *Fusconaia subrotunda*.

Additional *Pegias* valves have been collected at Ritner Ford 3.2 km upstream from Freedom Church Ford [WCS CU/BS-1 (2)] indicating that the Little South Fork population is widespread in riffle areas of the river. The Little South Fork originates in Pickett County, Tennessee, and stretches some 41.6 km along the Wayne/McCreary County line in Kentucky to its confluence with the Big South Fork Cumberland River. Considerable additional habitat may be extant upstream from Ritner Ford. However access to this area is limited and it has not been assessed thus far. The Little South Fork is perhaps the most pristine stream remaining within the entire known range of *Pegias* in the Cumberland and Tennessee drainages.

While analogous habitat occurs in the Big South Fork Cumberland River, additional populations are not expected there. In recent years, increases in coal surface mining has increased siltation and decreased water quality to the point that the mollusk population is declining rapidly and will perhaps soon disappear.

The discovery of a substantial and perhaps the healthiest, population of *Pegias fabula*in the Little South Fork Cumberland River constitutes a significant addition to the known distribution of this rare mollusk. If the Little South Fork, which is designated a Kentucky Wild River, continues to enjoy protection from strip mining and other perturbations, its mussell population should be afforded continued preservation. This suggests that perhaps the status of *Pegias* should be regarded as threatened rather than endangered.

We thank David H. Stansbery, OSUM, for provision of information and deposition of specimens.

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DISTORSIO KURZI, A NEW CYMATIID GASTROPOD FROM THE CENTRAL PHILIPPINES

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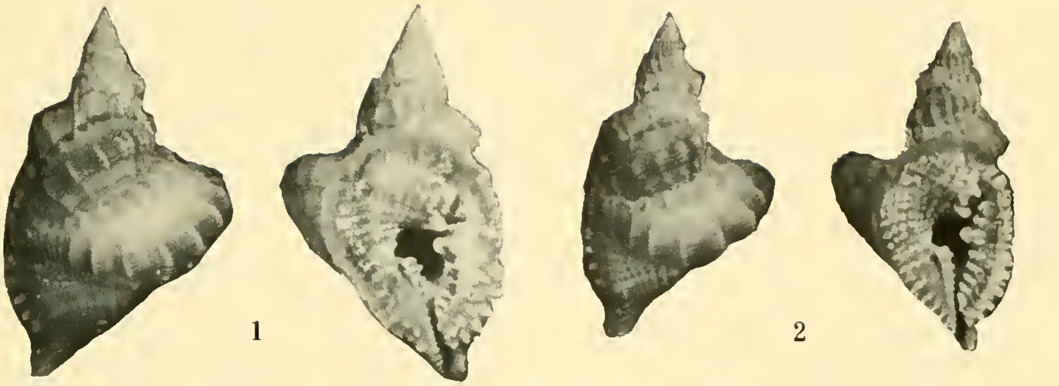
Over the last few years there has been increased interest in commercial shell collecting in the deeper waters of the central Philippines. This



FIGS. 1-2. Distorsio (Rhysema) kurzi *new species.* **1,** *Holotype, USNM 783780, off Balicasag, Bohol Island, Philippines, in 120-150 meters (1 ×).* **2,** *Paratype, USNM 783931, same locality and depth (1 ×).*

has brought to light many new and unusual species from previously unsampled offshore communities. Among these is a new Cymatiidae species of *Distorsio* described herein.

Distorsio (Rhysema) kurzi new species

Figs. 1 and 2

Description: Shell to 56 mm; spire angle 45°-50°; protoconch with 2 whorls, smooth, glassy; teleoconch with 7-9 whorls; first 4 whorls conical; beginning with 5th whorl there is a swollen bulge with the parietal shield 180° in apposition, unit arrangement repeating every 270°; shell strongly sculptured with beads or ribs at intersections of spiral cords and axial ribs; spiral sculpture consists of 1 major cord at the suture, 1 at the sharply angled shoulder (comprising 8 coalescing threads), 5 major cords below the shoulder, and 4 or 5 on the siphonal canal. Shell color deep golden brown with darker brown bands at the shoulder and the suture; parietal shield thin, lenticular, coffee to orange-brown in color, with white denticulations; 8 denticles on inside of outer lip; anterior 5 produce white denticles on outer lip with white chevrons between; 6th denticle greatly enlarged, protruding into aperture opposite corresponding indentation in columella; 13-16 white denticles on columellar side of siphonal canal below the indentation.

Type material: Holotype — United States National Museum (USNM 783780), length 51 mm; paratypes in the United States National Museum, Washington, D.C. (USNM 783931).

Type locality: Off Balicasag, Bohol Island, Philippines, in 120-150 meters.

Range: Known only from the type locality.

Discussion: This new species is a component of the lower continental shelf communities that surround the deep water pockets between the islands of the central Philippines. *Distorsio kurzi* most closely resembles the Japonic *D. constricta habei* (Lewis, 1972:38-44, figs. 38, 39) but differs primarily by having a sharply angled shoulder that produces the characteristic pronounced humps. The new species is more darkly colored than *D. constricta habei,* being consistently golden brown, with a darker mid-body band, brown parietal shield and outer lip, as opposed to the pale-tan to white body color and white parietal shield of *D. constricta habei.* The number of denticles on the columellar edge of the siphonal canal also consistently differs between the two species; 8-12 in *D. constricta habei* and 13-16 in *D. kurzi.*

The new taxon honors Richard M. Kurz, Wauwatosa, Wisconsin, who first recognized the species as new and donated the type material.

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SEASONAL VARIATIONS IN GROWTH OF THE ASIATIC CLAM, *CORBICULA FLUMINEA* (BIVALVIA: CORBICULIDAE) IN A SOUTHERN ILLINOIS FISH POND

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ABSTRACT

Fifty specimens of the Asiatic clam were stocked into a 0.06 ha fish pond for 62 days during the summer, and 40 days for both fall and winter. Clam recovery for summer, fall, and winter observations was 82%, 60%, and 98%, respectively. Clam growth rates for summer and fall averaged 0.012 mm/day and 0.054 g/day, while winter growth rates averaged 0.003 mm/day and 0.0003 g/day. Summer and fall growth rates were not significantly different (P = 0.29), while winter growth rates were significantly lower (P = 0.001). Relative weight gain per day for all observations was significantly greater (P = 0.01) for smaller clams. Absolute weight gain per day was significantly greater (P = 0.006) for larger clams during the summer, while fall and winter absolute growth was similar for all clams. Summer, fall, and winter water temperatures were significantly different (P = 0.001), while phytoplankton density remained relatively constant for all observations.

INTRODUCTION

Corbicula fluminea (Müller)[1] was first collected in the United States from the Columbia River, Washington in 1938. Subsequently it has become established in all river drainage systems except the Great Lakes and Northeast (Sinclair and Isom, 1963; Sickel, 1976; and Gardner, *et al.*, 1976). Presently *Corbicula* is considered a nuisance, possible subplanting native mollusks, causing economic problems in irrigation canals and power generating plants, and exhibiting periodic dieoffs (Sinclair and Isom, 1963; Bickel, 1966; and Sickel, 1976). Although the ecological preferences, range, and economic importance of *Corbicula* are well-documented by Heinsohn (1958); Sinclair and Isom (1963); and Rinne (1974), the biology of the clam itself is poorly known. Few studies exist on *Corbicula* growth rates and none on seasonal variations in growth (Sinclair and Isom, 1963; Rinne, 1974; O'Kane, 1976; and Sickel, 1976). The purpose of this investigation was to determine daily and seasonal growth rates of *Corbicula*, and effects of clam size on absolute and relative growth rates in a southern Illinois fish pond.

[1] Also known as *Corbicula manilensis* (Philippi) and *leana* Lea.

MATERIALS AND METHODS

Fifty specimens of *Corbicula* were labeled with nail polish, measured to the nearest 0.1 mm, and weighed to the nearest 0.01 g. Linear values were obtained from length measurements and weight values after test clams were cleaned and blotted dry. Two open top cages, each 0.3 m² and 9 cm deep, were filled to a depth of 3 cm with substratum obtained from the test pond. Twenty-five clams were placed on the substratum of each cage and stocked into a 0.06 ha pond (Table 1). Cages containing clams were placed on the pond substratum in 0.5 m water. Summer, fall, and winter runs were initiated on 20 July, 22 October, and 6 December, respectively. Surface water temperatures were recorded between 0700 and 0900 daily. Phytoplankton samples were collected with an integrated column sampler, fixed, preserved, identified, and counted as described by Vollenweider (1969). Upon termination of each run recovered clams were measured to nearest 0.1 mm and weighed to nearest 0.01 g. all statistical examinations were by multiple regression analysis.

TABLE 1. *Summary of* Corbicula *stocking data for all observations.*

Parameter	Summer	Fall	Winter
No. Clams Stocked	50	50	50
Wt. Clams Stocked (g)	0.95-8.15	1.14-9.34	1.28-11.10
Ln.[1] Clams Stocked (mm)	14-29	15-30	15-32
Density Stocked (No./m^2)	78	78	78
Density Stocked (g/m^2)	256	273	299
Duration of Run (days)	62	40	40

[1] Ln. equals length.

RESULTS AND DISCUSSION

Low recovery of clams during the fall was very likely due to muskrat predation (Table 2). Muskrat tracks were found along the shoreline and digging marks observed in the substratum of test cages. Clams not recovered were lost, no labeled empty shells were collected. Surface water temperatures were significantly different for all seasons, while phytoplankton numbers remained relatively constant (Table 2). Phytoplankton was dominated by chlorophytes in summer and chrysophytes in winter. Fall phytoplankton populations were dominated by varying ratios of chlorophytes and chrysophytes.

Corbicula grew throughout the year, even in winter when water temperatures averaged 3.0° C. The presence of a crystalline style in 80% of *Corbicula* examined on 22 February, when the pond

TABLE 2. *Summary of* Corbicula *growth and related parameters.*

Parameter	Summer (S)	Fall (F)	Winter (W)	S vs. F (P)	F vs. W (P)
% Clams Recovered	82	60	98	-------	--------
Avg. Dawn Water Temp. at Surface(°C)	24.7 (1.8)	11.2 (3.4)	3.0 (1.4)	0.001	0.001
Avg. No. Phytoplankton per liter x 10^6	9.8 (5.6)	7.1 (1.9)	10.0 (5.0)	0.51	0.22
Avg. Inc. in Ln. (mm) per day x 10^{-3}	12.1 (8.6)	12.1 (7.6)	2.6 (3.0)	0.97	0.001
Avg. Inc. in Wt. (g) per day x 10^{-3}	57.3 (3.4)	50.3 (1.4)	0.3 (0.4)	0.29	0.001

(P) is an abbreviation for probability and numbers in parenthesis are standard deviations.

was ice-covered and water temperature 4.2° C, indicates clams were still ingesting. According to Pennak (1978) the crystalline style is present only in actively feeding clams and disappears when ingestion is not occurring. Growth of *Corbicula* in winter was also observed by Sickel (1976), but at greatly reduced rates. However, Gale and Lowe (1971) found *Sphaerium transversum* to cease ingestion at 2-4°C and Mackie and Quadri (1978) observed no growth in *Musculium securis* at temperatures less than 10° C.

Corbicula growth during summer and fall was similar, although water temperatures averaged 24.7° C and 11.2° C, respectively (Table 2). Similar findings were reported by Gale and Lowe (1971) working with *S. transversum.* They observed maximal ingestion to occur in spring, early summer, and fall. O'Kane (1976) found *Corbicula* to grow best at temperatures in excess of 24.0° C and reported length increases averaging approximately 4.4×10^{-2} mm/day. However, *Corbicula* respiration has been observed to decrease rapidly at temperatures in excess of 30° C, McMahon and Aldridge (1976). Sickel (1976), employing frequency distribution techniques, found length increase in *Corbicula* ranging from 7.2×10^{-2} mm/day to negative growth. The limited growth data available from literature is quite similar to the values we observed for *Corbicula.*

Absolute growth for *Corbicula* in summer was directly related to clam size. Clams 4.0 g and larger gained significantly ($P = 0.006$) more weight per day than smaller clams. In fall and winter absolute weight gain per day of large and small clams was not significantly different ($P = 0.73$ and $P = 0.46$, respectively). Relative growth for *Corbicula* during all seasons was inversely related to size. Smaller clams gained a significantly ($P > 0.01$) greater percentage of body weight per day than did larger clams.

ACKNOWLEDGMENTS

We would like to acknowledge assistance provided for this investigation by the Cooperative Fisheries Research Laboratory at Southern Illinois University—Carbondale and Sigma Xi, the Scientific Research Society.

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DEATHS

John Marwick, New Zealand paleontologists, died at Hawkes Bay, New Zealand, on August 16, 1978, at the age of 87. He emigrated from Scotland in the 1880's and became noted for his work on Tertiary mollusks. An excellent biography of him was published in *Nature,* vol. 276, p. 428, Nov. 1978.

Mina May Slinn, amateur conchologist of St. Petersburg, Florida, died July 29, 1979, at the age of 69. She was an active collector and writer on shells for several Florida shell clubs.

CADULUS TETRASCHISTUS (WATSON), AN EARLIER NAME FOR *C. QUADRIDENTATUS* (DALL) AND *C. INCISUS* BUSH (SCAPHOPODA)

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ABSTRACT

Cadulus quadridentatus *(Dall, 1881) and* Cadulus incisus *Bush, 1885 are junior subjective synonyms of* Cadulus tetraschistus *(Watson, 1879), based on an examination of typological and other specimens. The range of this taxon is from North Carolina and Bermuda, to Argentina, as far south as the Gulf of San Matías. Comparisons are made with* Cadulus tetrodon *Pilsbry and Sharp, 1897, which is considered to be a valid species.*

Siphodentalium tetraschistum Watson (1879: 521) was based on an empty shell dredged by the "Challenger" Expedition, Station 113A, off Fernando de Noronha Island (Brazil), between 7 and 25 fathoms (13 and 46 meters). A detailed description was provided, but the illustrations appeared later (Watson, 1886:pl. 2, Fig. 8a-d). Watson (1885:16) compared his taxon with *Siphodentalium bifissum* Wood, *S. lofotense* Sars, and *S. vitreum* Sars.

Siphonodentalium quadridentatum was described by Dall (1881:36) from a lot dredged off the west coast of Florida in 30 fathoms (55 meters). He considered this nominal species to be closely related to Watson's taxon, mentioning that the description agreed almost exactly with the Floridian specimens. Later Dall (1889a:428) cited specimens as *Cadulus quadridentatus* from "... Fernando de Noronha, 7 - 25 fms.," without an explanation. The same year, Dall (1889b:295) extended the range south to the mouth of the Rio de la Plata ("Albatross" Station 2765).

The status of these nominal species became confused further when Pilsbry and Sharp (1897: 148) treated Dall's species, together with *Cadulus incisus* Bush, 1885, as varieties of *C. tetraschistus* Watson, proposing Bush's species as intermediate in form between the extremes represented by the other two taxa. The confusion was compounded when Henderson (1920:97-101) separated *tetraschistus* and *quadridentatus*, and further separated the latter into two subspecies, the nominate and *C. quadridentatus acompsus* Henderson.

In 1938 and 1942 respectively, Carcelles, and Carcelles and Parodiz identified *Cadulus tetrodon* Pilsbry and Sharp, 1897, from stomachs of starfish taken off Puerto Quequen (Buenos Aires, Argentina). These specimens (*ex* Museo Argentino de Ciencias Naturales, MACN 23156) and deposited in the Museum of Comparative Zoology (MCZ 118674) are now labeled as *Cadulus tetraschistus*. Turner (1955:314) identified (together with Carcelles' specimens) a lot taken in 7 fathoms in the Rio de la Plata by the "Hassler" Expedition, as *C. tetraschistus*. She recognized Watson's species as inhabiting southwestern Atlantic waters, ranging from Fernando de Noronha to Uruguay, and she considered *Cadulus quadridentatus* to occupy areas from the Caribbean Sea to North Carolina and Bermuda, a view held by Penna-Neme (1974:114-117). Scarabino (1970; 1973) and Rios (1970) cited the range of *C. quadridentatus* from North Carolina to northern Argentina in depths to 42 meters, and limited *C. tetraschistus* to Fernando de Noronha.

While checking the collections of several South and North American Institutions, we examined a large series of specimens assigned to these nominal species and compared them with the pertinent type material. When the type specimens of *Cadulus quadridentatus* (MCZ 7739) and *Cadulus tetraschistus* (BM/NH 1887.2.9.66) were compared we did not find enough differences to consider them as separable species. Watson's type (Fig. 1a) is a relatively immature example in a very satisfactory state of preservation, while Dall's (Fig.

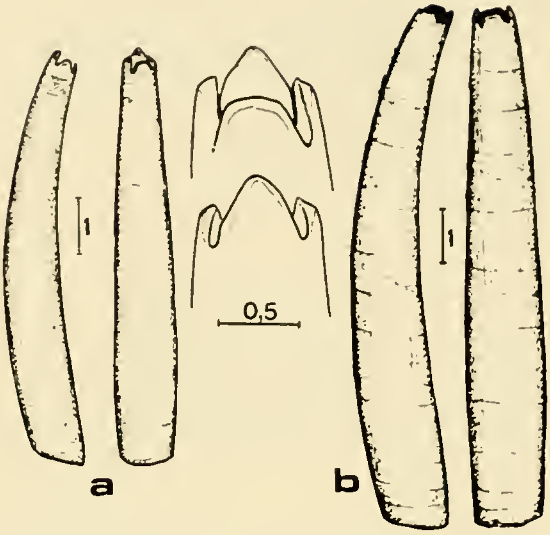

FIG. 1. Cadulus tetraschistus *(Watson, 1879) camera lucida drawings.* **a**, *Type of* C. tetraschistus *(BM/NH 1887.2.9.66).* **b**, *Type of* C. quadridentatus *(Dall, 1881) (MCZ 7739). Scales in millimeters.*

1b) is a little larger and has lost the dorsal lobe. We must conclude that *Cadulus quadridentatus* and *Cadulus incisus* Dall (holotype in USNM 44860) are conspecific with *C. tetraschistus*, the latter name having priority.

The "remote longitudinal texture ..." mentioned by Watson (1879:521) which was the only feature that kept us from uniting these species, was found not to be an external feature and to be probably due to internal irregularities formed during the construction of the shell or perhaps due to the process of drying after coming from the ocean. This characteristic feature is very often observed in specimens of this and other species of the family.

At the Academy of Natural Sciences of Philadelphia, we examined three lots (ANSP 35574, 35575, and 75744) formerly labeled as *tetraschistus*, but the labels had been changed to read *"quadridentatus"*.

Syntypes of *Cadulus tetrodon* Pilsbry and Sharp in the Academy of Natural Sciences (ANSP 71070) have characteristics that caused us to believe it to be a distinct species.

The known distribution of *C. tetraschistus* is from North Carolina, Bermuda, the Caribbean Sea, Fernando de Noronha (Brazil), Uruguay and Argentina as far as the Gulf of San Matías (42° S. Lat.), with a bathymetrical range of three to 120 meters, on largely sandy substrates (Scarabino, 1975:182). *Cadulus tetraschistus* is reported from the Upper Miocene and Pliocene of Florida and Venezuela (Weisbord, 1964:134).

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MUSSELS OF FLOYD'S FORK, A SMALL NORTHCENTRAL KENTUCKY STREAM (UNIONIDAE)

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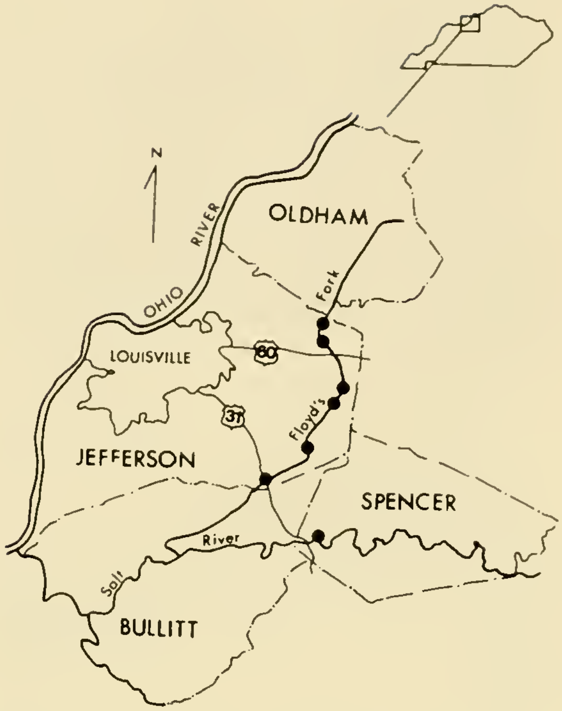
ABSTRACT

A survey of the mussels of Floyd's Fork, a small northcentral Kentucky tributary of the Salt River, was carried out during the summer of 1978. Six stations were collected in Floyd's Fork with a seventh station being located on Salt River near the confluence of the two streams. Twenty-five species were collected. Of these Quadrula nodulata, Lampsilis teres, *and* Corbicula leana *are reported for the first time as occurring in the Salt River drainage. Floyd's Fork appears to be a stream of high water quality which supports a healthy, rather abundant, highly diversified mussel fauna.*

A number of surveys of the naiad faunas of major streams in Kentucky have been effected over the last fifty years. Ortmann (1926), Stansbery (1965, 1969), Clench and van der Schalie (1944), Isom (1969), Blankenship and Crockett (1972) and Williams (1969) have looked at such streams as the Ohio, Cumberland, Tennessee, Green, Kentucky and Rockcastle Rivers. Stansbery (1978) is at the present time working on the Licking River in eastern Kentucky.

There is, however, a dearth of papers dealing with faunas of smaller streams. Stansbery (1978) implies that in this time of rapid extinction of aquatic organisms, as a result of habitat destruction or modification, many species have been extirpated from the main waterways and may exist only in isolated refugia well up into the headwaters of smaller streams. These smaller tributaries most often do not suffer from pollution (urban sewage, industrial, mining, etc.) to as great a degree as do larger streams.

This paper reports on work carried out in such a stream, Floyd's Fork, located in northcentral Kentucky. Floyd's Fork originates in northeastern Oldham County near the village of Ballardsville and meanders for nearly 80 km across the county, through adjacent Jefferson County, and terminates in Bullitt County at its confluence with the Salt River. Salt River is a fairly large tributary of the Ohio River and joins



with the Ohio approximately 30 km downstream of Louisville, Ky. within the boundaries of the Fort Knox Military Reservation (see map of study area).

Throughout the summer of 1978 six sites were collected along Floyd's Fork. In addition a seventh site was located on Salt River just upstream of the point of merger of Floyd's Fork with Salt River. Clench and van der Schalie (1944) and Rosewater (1959) have previously collected in the Salt River. However their activities were centered near Bardstown, Nelson County, Kentucky (approx. 50 km upstream and east of the site reported here). I have been unable to find an account of work having been done previously on Floyd's Fork.

METHODS

All specimens were hand-picked. Only live specimens or fresh empty shells were retained. Live specimens were obtained for all of the species listed below except *Lampsilis teres* which was found only as fairly old dead shells. Most of the material collected is presently housed at Marshall University with a series of voucher specimens also having been deposited with the Ohio State Museum of Zoology (OSUM #42269-42310).

Collecting stations

1. Floyd's Fork Creek at Aiken Rd. Bridge. Aiken Rd. exits U. S. Highway 60 approximately 3 km E. of Middletown, Ky. (Jefferson Co.)
2. Floyd's Fork Creek at Beckley Station Rd. Beckley Sta. Rd. exits U.S. Highway 60 approx. 6 km East of Middletown and intersects County Rd. 1531 after fording Floyd's Fork. (Jefferson Co.)
3. Floyd's Fork Creek at State Rd. 155 bridge, 1.5 km E. of Fisherville, Ky. (Jefferson Co.)
4. Floyd's Fork at County Rd. 1531 bridge, 300 m South of intersection with State Rd. 155, 3 km West of Fisherville, Ky. (Jefferson Co.)
5. Floyd's Fork at U.S. Highway 31-E bridge, 1 km North of Bullitt Co. line. (Jefferson Co.)

TABLE 1. *List of species collected from Floyd's Fork Creek and Salt River. Relative abundance indicated as follows: (C = common, M = moderately common, R = rare).*

Species name	Abund.	Site Number 1	2	3	4	5	6	7
Fusconaia flava (Raf.)	C	x					x	
Megalonaias nervosa (Raf.)	C							x
Amblema plicata (Say)	C					x	x	x
Quadrula pustulosa (Lea)	M					x		x
Quadrula nodulata (Raf.)	R							x
Quadrula quadrula (Raf.)	M							x
Tritogonia verrucosa (Raf.)	C						x	x
Pleurobema clava (Lam.)	M						x	
Elliptio dilatatus Raf.	R						x	
Lasmigona costata (Raf.)	M					x		x
Lasmigona complanata (Barnes)	C	x			x	x	x	x
Anodonta imbecillis (Say)	R						x	x
Anodonta grandis Say	C	x	x	x	x	x	x	
Alasmidonta viridis	C	x	x	x	x	x	x	
Strophitus undulatus (Say)	C	x		x	x	x	x	
Ptychobranchus fasciolaris (Raf.)	M				x			x
Obliquaria reflexa Raf.	R							x
Truncilla truncata (Raf.)	M			x	x			
Leptodea fragilis (Raf.)	M		x	x	x	x	x	x
Potamilus alatus (Say)	M					x	x	x
Toxolasma parvus (Barnes)	R					x	x	
Lampsilis teres (Raf.)	R							x
Lampsilis r. luteola (Lam.)	C	x	x	x	x	x	x	x
Lampsilis ventricosa (Barnes)	M	x	x		x	x	x	x
Corbicula leana Prime				x			x	

6. Floyd's Fork at bridge on Seatonville Rd. (County Rd. 1819) 1.6 km West of the village of Seatonville. (Jefferson Co.)
7. Salt River, Off County Rd. 1060 at Confluence of Goose Creek with Salt River. 3 km S.W. of the village of Waterford, Ky. (Spencer Co.)

RESULTS AND REMARKS

A total of twenty-five species were collected during this study. Of this number five species *(Megalonaias nervosa, Quadrula nodulata, Quadrula quadrula, Obliquaria reflexa,* and *Lampsilis teres)* were found only in the Salt River. *Quadrula nodulata, Lampsilis teres,* and *Corbicula leana* [also called *manilensis* and *fluminea* — editor] are reported here for the first time as occurring in the Salt River drainage.

The presence of *Corbicula* far upstream in Floyd's Fork (Sta. #3) is another indication of just how cosmopolitan this introduced Asian species has become. Sinclair and Isom (1961) reported the presence of *Corbicula* in the Ohio River (for the first time) based on specimens collected near Paducah, Ky. in 1957. Other authors place the time of arrival of *Corbicula* in the area of the confluence of Salt River with the Ohio at around 1963. If one assumes a route of dispersal from the Ohio River, to Salt River, to Floyd's Fork Station #3, one must assume a fairly remarkable rate of range expansion equal to 100 km/15 year period of time or approx. 6.6 km/year.

The overall number of species, and large numbers of individuals of each species present, indicates a stream of rather high water quality and a bivalve population that is both stable and healthy.

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I wish to thank Dr. David H. Stansbery of the Ohio State University Museum for confirming identifications for me.

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A NEW FOSSIL *RADIOCENTRUM* (PULMONATA: OREOHELICIDAE) FROM NORTHERN COAHUILA, MEXICO

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ABSTRACT

A new species of oreohelicid land snail, Radiocentrum orientalis, *is described from the Serranias del Burro, a mountain range of northern Coahuila, Mexico. Specimens are fossils from probable Pleistocene deposits. This is the easternmost record of the genus. Distribution of the genus in Mexico is discussed.*

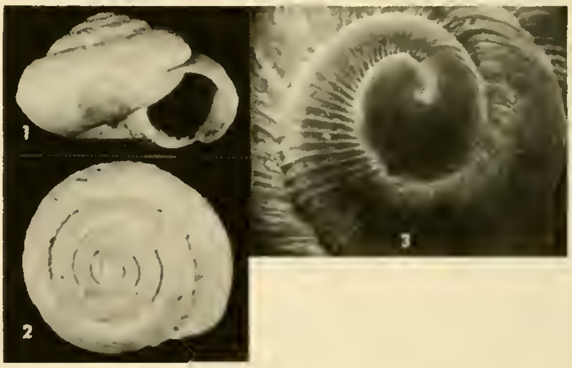
Recognition of the taxon *Radiocentrum* as a separate genus in the family Oreohelicidae was recommended by Babrakzai, Miller and Ward (1975) and was followed by Christensen and Miller (1976). Formerly *Radiocentrum* had been considered a subgenus of *Oreohelix.*

The present species is described from fossil shells, probably of Pleistocene age (judging by the massive canyon fill in which they occur and the nature of the associated molluscan fauna). Specimens were collected on an expedition arranged by Mr. David H. Riskind, Texas Parks and Wildlife Department, and Mr. Robert Burleson, Temple, Texas, to whom I am indebted.

Radiocentrum orientalis *n. sp.*
(Figs. 1-3)

Diagnosis: Although poorly preserved, specimens of this species exhibit (1) the riblets (Fig. 3) that are characteristic of the embryonic whorls of *Radiocentrum* and (2) the narrower, more deeply impressed early whorls (Fig. 2) of that genus as contrasted with *Oreohelix.* It differs from most species of *Radiocentrum* in possessing an elevated spire, a characteristic found, elsewhere, only in species of the Chiricahua Mountains, Arizona. However, kinds described from the Chiricahua Mountains are variously wider, thinner-shelled, more carinate or bear spiral striae, in contrast to the species described here.

Description of Holotype: Fossil shell, heavy (thick-walled), 11.8 mm in diameter and 7.9 mm high, elevated, with spire forming angle of 123°, spire protrusion 2.1 mm; body whorl with upper lip of aperture descending to immediately below angularity; aperture subrounded, 4.7 mm wide and 4.5 mm high (excluding walls), aperture oriented obliquely at angle of 35° to vertical; umbilicus narrow, 1.7 mm wide, slightly overlapped by lower lip, contained 6.9 times in shell diameter; tightly coiled with 5.5 whorls; sutures of early whorls deeply impressed; shell surface has suffered loss of periostracum; radial ribs appear dimly on last 1/4 of embryonic whorl and continue to 1.7 whorls; thereafter appear growth wrinkles, these becoming increasingly coarser and more irregular in occurrence on body whorl, dorsally; ventral surface of body whorl smoother with a few low growth wrinkles; shell bleached, mainly white except for some tannish color on whorls 1.5 to 3 (no evidence of color bands).



FIGS. 1-3. Radiocentrum orientalis *new species.* 1 *and* 2, *Apertural and dorsal views of holotype (11.8 mm. diameter; USNM 758820);* 3, *Apical whorls of a paratype (scanning electron micrograph, courtesy of Dr. W. R. Roser).*

Paratypes: Only eight paratypes were secured, all smaller than the holotype and some damaged by breakage. On some of these smaller shells the riblets of the embryonic whorls, typical of the genus, are better preserved (Fig. 3).

Etymology: L. *orientalis*, of the east, in reference to the occurrence of this species farther east than other known members of the genus *Radiocentrum*.

Disposition of Types: Holotype, USNM 758820. Paratypes: University of Arizona 6258; University of Texas at El Paso 5647, 5660.

Type Locality: MEXICO, Coahuila, Mcpo. de Villa Acuna, Serranias del Burro, 29°00′30″N; 102°05′55″W. Upper end of Canon el Bonito at *ca.* 1680 m; 200 m up-canyon from a concrete stock tank *(pila);* from sediments exposed on west wall of canyon, 5-10 m above canyon floor. These sediments underlie a fan of mixed alluvium and colluvium, which has been dissected by the arroyo in the floor of the canyon. A single shell was found in sediments approximately 1.5 km up-canyon, northward, from the type locality.

Associated Fauna: Fossils associated with *R. orientalis* at the two localities noted above were the following (asterisk indicates species not found living in the area): **Cochlicopa lubrica* (Müller), **Pupilla blandii* Morse, **Vallonia gracilicosta* Reinhardt, a succineid, sp. indet., **Rabdotus dealbatus* (Say), **Discus cronkhitei* (Newcomb), *Helicodiscus eigenmanni* Pilsbry, *Retinella (Glyphyalinia) indentata paucilirata* (Morelet) and *Zonitoides arboreus* (Say). The high proportion of species not found at present in this and nearby canyons suggests a markedly different paleoenvironment. It seems likely that these snails lived during a glacial age of the Pleistocene. The present fauna has a marked affinity to that of the Sierra Madre Oriental of Mexico, to the southeast, in contrast to the fossil assemblage.

DISCUSSION

Reports of oreohelicids from Mexico have all appertained to the genus *Radiocentrum*. These records are exceptionally widely scattered. Two species have been described from Baja California Sur (Miller, 1973; Christensen and Miller, 1976), two species from northwestern Chihuahua (Pilsbry, 1948) and one species from southeastern Chihuahua (Drake, 1949). The Serranias del Burro of Coahuila are some 1000 km distant from Baja California Sur and 380 km from the type locality of *R. almoloya* (Drake), 1949, near Salaices, Chihuahua. It is likely that lack of collecting in the mountains of northern Mexico, especially of Pleistocene fossil gastropods, may account for this scattered distributional pattern. It is also possible that this is a venerable genus in Mexico and one in which rifting in the Gulf of California and uplift of the Sierra Madre Occidental (and other ranges) may relate to disjunctions in distribution.

Shells of *R. almoloya*, like those of *R. orientalis*, appear to me to be fossil. Possibly the genus *Radiocentrum* may no longer exist in the former, eastern part of its range. There seems a general pattern of extirpation of oreohelicid snails in the southeastern part of the range of the family. Thus, fossil shells, only, are known from the Sierra Rica, Tres Hermanas, Florida, Cooke, Caballo and San Andres Mountains of southern New Mexico and from the Franklin, Hueco and Guadalupe Mountains of Texas. The Sacramento Mountains of New Mexico are rich in fossil oreohelicids but the only living species there, *Oreohelix strigosa nogalensis* Pilsbry, 1939, is of restricted occurrence. All this suggests inability of these southeastern oreohelicids to adjust to regional climatic changes.

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OBSERVATIONS ON THE TERRESTRIAL GASTROPODS IN THE VICINITY OF JASPER, ALBERTA (CANADA)

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ABSTRACT

Fourteen species of terrestrial gastropods were collected in the vicinity of Jasper, Alberta, from April through September, 1976. Zonitoides nitidus, Retinella electrina, Striatura ferrea *and* Pupisoma *sp. are new locality records for the province of Alberta.*

There are few published records of terrestrial molluscs in Alberta. The majority of these reports (Taylor, 1895; Berry, 1922 and Mozley, 1926, 1931) deal with the mollusc fauna of the Rocky Mountain regions of the province. There are no recent reports, to my knowledge, of terrestrial gastropods from Alberta.

An intensive investigation designed to identify the molluscan intermediate host(s) of *Parelaphostrongylus odocoilei* (Nematoda: Metastrongyloidea), a parasite of mule deer (*Odocoileus hemionus hemionus*), resulted in the collection and identification of approximately 8,500 terrestrial gastropods in the general vicinity of Jasper, Alberta (Platt, 1978). The majority of the molluscs reported herein have been recorded in previous investigations of the mollusc fauna of the Rocky Mountains in Alberta. Several gastropods found during the present study have not previously been reported from Jasper.

METHODS

Molluscs were collected weekly from 23 April to 24 August 1976, with the exception of the third week in May and the second week in July. Two additional collections were made on 7-8 and 21-22 September. Mollusc identifications were made with the aid of Burch (1962) and Pilsbry (1946, 1948). All collections were done by hand. A variety of natural material (logs, rocks and leaf litter) was examined for gastropods as well as man-made debris.

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STUDY AREAS

Jasper, Alberta (53°32′N, 113°36′W) is approximately 400 km west of Edmonton, in the eastern foothills of the Rocky Mountains. The townsite (Fig. 1) is situated in the center of Jasper National Park. Five collecting sites, all located within 5 km of the townsite, were selected on the basis of major vegetation types. Elevation of the sites ranged from 1120 m (Areas I and II) on the floor of the Athabasca Valley to 1500 m at area V (Fig. 1).

Area I (Fig. 1) is an open, grassy area adjacent to the Highway 16 by-pass, east of the townsite. This area was disturbed by the construction of the highway and contains a number of large rocks that are potential mollusc refuge sites. Native and introduced grasses are the predominant vegetation. A few juniper (*Juniperus* sp.) and bearberry (*Arctostaphylos uva-ursi*) are present, as well as lodgepole pine seedlings (*Pinus contorta*).

Area II is a canopied region adjacent to Area I, bordered on the east by the Athabasca River (Fig. 1). The predominant vegetation is lodgepole pine, interspersed with aspen (*Populus tremuloides*). The predominant shrubs are juniper, bearberry, and buffaloberry (*Shepherdia canadensis*). There is a large variety of material (man made) for refuge sites, as well as an abundance of natural material (aspen and lodgepole pine logs).

Area III is a transition area between valley and mountainous habitat, directly west of the townsite (Fig. 1). There is a sharp transition and

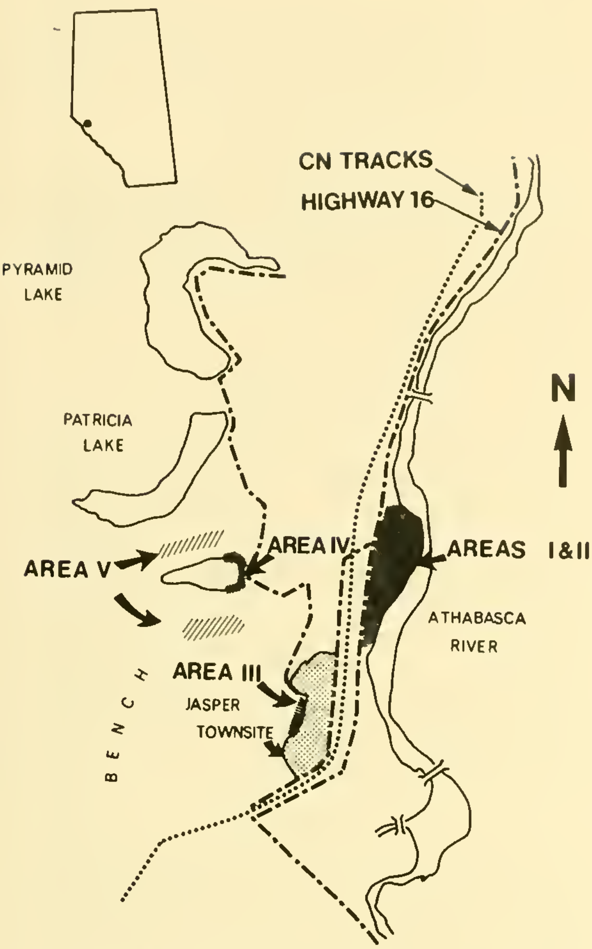

FIG. 1. *Diagrammatic representation of the Jasper Townsite (Jasper, Alberta), indicating the areas of mollusc collection.*

a dramatic increase in elevation. The predominant vegetation is grass and an occasional lodgepole pine. Buffaloberry, bearberry and juniper are common.

Area IV is situated northwest of the townsite (Fig. 1). It is a marshy zone with sedge (*Carex* sp.) as the predominant vegetation.

Area V consisted of two disjunct stands of aspen, surrounded by and interspersed with lodgepole pine. These sites are located north and south of Area IV (Fig. 1). Bearberry, buffaloberry and juniper are the most common shrubs.

MOLLUSCS

A summary of all molluscs collected, the area of collection and previous reports in Alberta is given in Table 1.

Limacidae

Deroceras laeve (Müller) has previously been reported from Alberta as *Limax hyperboreas* by Taylor (1895) and *Agriolimax hyperboreas* by Mozley (1931). Pilsbry (1948) clearly regards *A. hyperboreas* as a synonym of *D. laeve.*

Deroceras laeve, the only slug encountered, was found in all areas examined. Individuals of this species were most commonly encountered in the open, grassy Area I, under rocks and, occasionally, other material. *Deroceras* was also common in Areas II and III, but scarce in Areas IV and V.

All the slugs collected were measured, while alive and in an extended position, to the nearest 0.1 mm with precision calipers. The mean length of *D. laeve* declined from 15.9 mm in April to late June to 12.3 mm in late July (Fig. 2) (t_s = 4.112; t_{∞} 0.001 = 3.291; P< 0.001) indicating a change in the population structure at this time and a single generation per year for *D. laeve* in the Jasper area.

TABLE 1. *Species and location of terrestrial gastropods collected in Jasper, Alberta (1976) with previous reports of these species in Alberta.*

Species	Locations Collected	Previous Reports From Alberta
Deroceras laeve	I,II,III,IV,V *	1,5 **
Euconulus fulvus	I,II,III,V	1; 2a,b; 3a,d
Zonitoides arboreus	I,II,III,V	1;2a,c; 3a; 4; 5
Zonitoides nitidus	I,II,III,V	new report
Vitrina limpida	I,II,III,V	2a; 4;5
Retinella electrina	I,V	new report
Striatura ferrea	V	new report
Discus cronkhitei	I,II,III,V	1;2a,b,c;3a,b,c;4;5
Discus shimeki	I,II,V	3a
Oxyloma retusa	IV	1;2a,b,c;4;5
Vertigo modesta	I,II,V	1;3a;4;5
Vertigo ovata	V	1;4;5
Columella edentula	II	1
Pupisoma sp.	I,II	new report

* see text for a description of the study areas.

** 1-Taylor (1893) Laggan (= Lake Louise); 2-Taylor (1895), a-35 miles east of Red Deer, b-MacLeod, c-Olds; 3-Berry (1922), a-Kanaskis, b-Morley, c-Waterton Lake, d-Bow River; 4-Mozley (1926) Jasper National Park; 5-Mozley (1931) Jasper National Park.

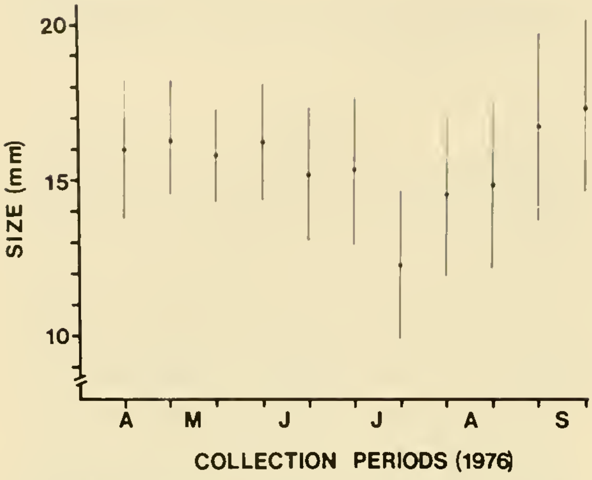

FIG. 2. *Mean lengths of* Deroceras laeve *collected in Jasper, Alberta. Bar represents one standard deviation.*

Zonitidae

Euconulus fulvus (Müller) was the most commonly encountered mollusc during this study. This species was found in all areas, with the exception of Area IV. *Euconulus* was the most abundant mollusc in Areas I and II, but was also common in Areas III and V.

Mozley (1926, 1931) reported *Euconulus chersinus polygyratus* from a variety of locations in Jasper National Park. *Euconulus fulvus* differ from *E. chersinus*, externally, in having fewer number of whorls, 5 1/2 to 6 1/2 – 7 1/2 (Pilsbry 1946). All specimens collected in the present study had 5 to 5 1/2 whorls and were unmistakably *E. fulvus*.

Zonitoides arboreus (Say) and *Zonitoides nitidus* (Müller) were collected in Areas I, II, III and V. *Zonitoides arboreus* was common in Areas I and II and more abundant than *Z. nitidus* in all locales. Both species of this genus were rare in Areas III and V.

This is the first report of *Z. nitidus* from Jasper, although it is considered "commonly distributed in the Canadian Zone" (Pilsbry, 1946). This species is widespread in the western United States (Pilsbry, 1946).

Vitrina limpida Gould was common during the latter half of the summer. The first individuals were collected during 19-21 July. Prior to this time the only evidence of *Vitrina* was the presence of large numbers of shells encountered while collecting.

Striatura ferrea Morse is a new record for Jasper and Alberta. This species was encountered infrequently (33 specimens) and it was restricted to the aspen-dominated Area V.

Retinella electrina (Gould) has not previously been reported from Alberta. Pilsbry (1946) includes Washington, British Columbia and Alaska in the range of this species. *Retinella* was also encountered infrequently (12 specimens) and was restricted to Areas I and V.

Endodontidae

Discus cronkhitei (Newcomb) was present in all areas with the exception of Area IV. This species was commonly encountered in Areas I and II, however, only a single specimen was found in Area III. *Discus cronkhitei* replaced *E. fulvus* as the most abundant mollusc in Area V.

Discus shimeki (Pilsbry) is a new record for Jasper. This species has been reported from the Kananaskis region (Berry, 1922). *Discus cronkhitei* was encountered most frequently in Area I, occasionally in Area II and a single specimen was found in Area V.

Succineidae

Oxyloma retusa (Lea) was restricted to the marsh (Area IV). This species was common and has been reported from Jasper and other locations in Alberta (Table 1).

Pupillidae

Vertigo modesta (Say) was the most common of the pupillids encountered during this study. It was found in Areas I, II and V, but most commonly in Area II.

Vertigo ovata Say was represented by a single specimen from Area V. Mozley (1931) reported *V. ovata* from very near the area examined during the present study.

Columella edentula (Drapanaud) was represented by three specimens collected in Area II. The range of *C. edentula* extends "across Canada" (Pilsbry, 1948). Taylor (1895) listed *Pupa simplex* from Laggan Alberta (=Lake Louise), which is regarded as a synonym of *C. endentula.*

Single specimens, referred to the genus *Pupisoma* Stoliczka, were collected from Areas I and II. The range of *Pupisoma* is restricted to the

southwestern United States (Pilsbry, 1948). However, with the high influx of tourists into Jasper, an accidental introduction is not unlikely.

DISCUSSION

The gastropod fauna in the areas examined is relatively homogeneous (Table 1). Areas I, II and V share 80% of the species that occur in any one of those areas. Area I and II share all but two species. *Striatura ferrea*, in the aspen-dominate Area V, and *Oxyloma retusa*, in Area IV, are the only specialists identified in the present study. The pupillids, *Vertigo ovata* (Area V) and *Columella edentula* (Area II) were encountered too infrequently to be described in these terms.

Stands of coniferous forest are generally considered to be poor mollusc habitat (Walker, 1902; van der Schalie, 1940). Recent reports (Clarke, *et al.*, 1968) in New Brunswick dispute these findings and furnish evidence that a variety of terrestrial gastropods inhabit coniferous forests. Area II in the present study is dominated by lodgepole pine *(Pinus contorta)*, interspersed with aspen. Ten species of molluscs, although not as abundant as in Area I, were collected from this stand. It is interesting to note that, although no quantification was attempted, the majority of molluscs collected were found in association with aspen or aspen logs that had fallen or been moved into the surrounding conifers. This is corroborated by a similar observation (Mozley, 1937) for terrestrial gastropods collected in nearby areas. Therefore, more specific mollusc-plant associations may provide "patches" for terrestrial molluscs.

The terrestrial gastropod fauna of Jasper is composed of generalists that have successfully adapted to the boreal regions (Mozley, 1937). The majority of these species have circumboreal distributions or have closely related sister-species in Eurasia (Likachev and Rammel'maier, 1952). The fauna of the townsite of Jasper lacks several species (6) that have been previously reported from the Park (Mozley 1926, 1931). These include *Vallonia albula*, *Cionella* (formerly *Cochliopa*) *lubrica*, *Succinea avara* and two species of *Oreohelix*, all of which would be expected to inhabit areas similar to those examined in this study.

ACKNOWLEDGMENTS

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BIVALVE MOLLUSCA OF THE YALOBUSHA RIVER, MISSISSIPPI[1]

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ABSTRACT

The bivalve fauna of the Yalobusha River in north central Mississippi was examined from 1973 to 1976. Of the 15 species found, 8 were not reported by Hinkley in 1906, whereas we did not find 13 of the species that he collected. There are four different types of habitat. Carunculina parva *was the main inhabitant of the upper portion of the river with its sandy substrate and sluggish low flow;* Sphaerium rhomboideum *was the dominant Mollusca of the reservoir; while* Quadrula pustulosa, Proptera purpurata, *and* Lampsilis anodontoides *composed the majority of the bivalves in the swift waters below the reservoir spillway.*

The bivalve fauna occupying the various aquatic habitats of the Yalobusha River in north central Mississippi was studied from 1973 through 1976. The river was sampled by Hinkley in 1906 during a study of Mollusca in selected streams in Mississippi and Alabama. Since that time the river's environment has been altered extensively from its original state of a meandering, wooded stream by channelization, the building of a 40-km² flood control reservoir, and changes in land use.

Although the molluscan fauna of most of the Mississippi River Basin has been well-documented, Hinkley's study (1906) is the only one from the northwest Mississippi area. He listed 34 species from Floating Creek, the Yalobusha, Tallahatchie, Big Black and Tombigbee rivers in Mississippi. Of those species, 16 were found in the Yalobusha River. Ortmann (1924, 1925) studied the molluscan fauna of the Duck and Tennessee rivers, and the mollusks of Alabama were investigated by Goodrich (1930) and van der Schalie (1938).

The objectives of the study were not only to determine species composition changes since land use and channelization have occurred but also to add to the knowledge of the taxa of Mollusca in Mississippi.

[1] Contribution of the U. S. Sedimentation Laboratory, USDA-SEA-AR, with the University of Mississippi.

Habitats

The Yalobusha River (Fig. 1) flows in an east-west direction through the sandy-loess hills of Mississippi cutting through Eocene and Paleocene formations forming a broad valley. Observations indicated that Mollusca occupied 4 major aquatic habitats: 1) river bottom; 2) reservoir littoral; 3) reservoir profundal, and 4) tailwaters below the reservoir spillway.

The river bottom substrate (Station 11) was mainly sand and gravel with a ripple-shallow pool combination along the dredged channel. Pools contained some clay and silt deposits. Water depths normally ranged from 0.05-0.2 m in ripples and 0.5 to 1.5 m in pools. Because the river and its immediate drainage has been channelized, runoff rates have increased and the stream was subject to flash flooding after moderate rainfall amounts. Thus the stream was subject to molar activity as well as scouring and redeposition of sediments.

The littoral zone of the reservoir was subject to water-level fluctuations, wave action and drawdown and had a substrate varying from sand or sandy gravel to gumbo or hardpan clay (Cooper, 1977). The profundal zone had more stable mud-muck bottom than the littoral zone and never experienced drawdown.

The spillway and tailwaters area below the dam (Station 13) created an artificial habitat of swift, turbulent waters. The channel center was a

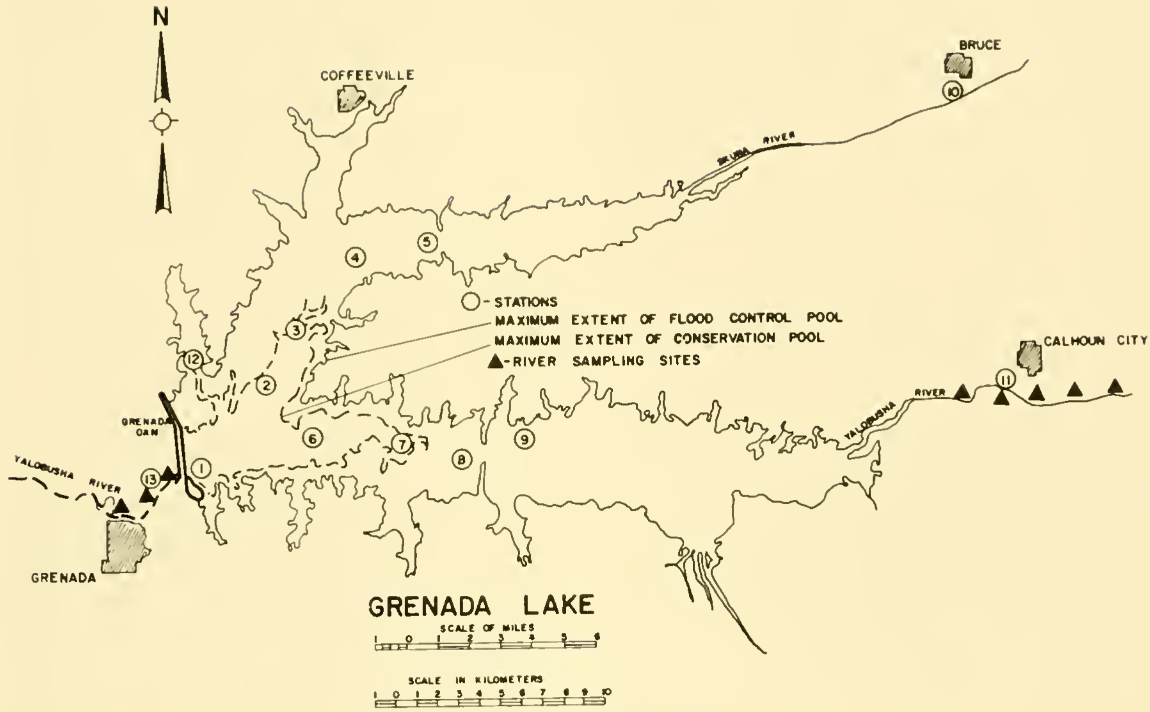

FIG. 1. *Map of study portion of the Yalobusha River, including Grenada Lake, Mississippi.*

sand-gravel cenosis or mud-muck bottom, and the sides were rock boulders laid by the U. S. Corps of Engineers to control channel erosion.

Collecting Methods

We collected in shallow river reaches by hand sampling and by dragging the bottom substrate with a D-frame dip net and sampled in the deeper water by Peterson and Ekman dredge hauls. Mollusca were taken in the swift waters below Grenada Reservoir by dredging and by hand sampling when spillway gates were closed. Lake samples were quantitative and taken in transects; however, most river sites had so few Mollusca that quantitative sampling was impossible. Turbidity levels made SCUBA sampling impractical in deeper areas. Representatives of all species of clams were verified by Dr. Henry van der Schalie of the University of Michigan. Voucher specimens are on file at the Department of Biology, University of Mississippi.

RESULTS AND DISCUSSION

Representatives of 15 species of Mollusca were

TABLE 1. *Taxonomic list of Bivalvia identified during the 1973-1976 study of the Yalobusha River including Grenada Reservoir with distribution by habitat, and those identified by Hinkley (1906).*

	1973-76 Occurrence	Hinkley (H) (1906)
Family Corbiculidae		
Corbicula manilensis (Philippi)	C	
Family Pisidiidae		
Eupera cubensis (Prime)	C	
Sphaerium rhomboideum (Say)	C	
Family Unionidae		
Subfamily Unioninae		
Plectomerus dombeyana (Valenciennes)	D	
Quadrula pustulosa (Lea)	D	
Uniomerus tetralasmus (Say)	A	H
Subfamily Anodontinae		
Anodonta corpulenta (Say)	D	H
A. imbecillis (Say)	O	
Subfamily Lampsilinae		
Carunculina parva (Barnes)	A	
Lampsilis claibornensis (Lea)	A	H
L. anodontoides fallaciosa (Simpson)	D	H
Leptodea fragilis (Rafinesque)	D	H
Obliquaria reflexa (Rafinesque)	D	
Proptera purpurata (Lamarck)	B,D	H
Villosa (Micromya) lienosa (Simpson)	A	

Distribution Code: A = Yalobusha River above Grenada Reservoir; B = Grenada Reservoir — littoral; C = Grenada Reservoir — profundal; D = Yalobusha River tail waters below Grenada Dam.

collected during the study (Table 1). Of the four species found in the upper portion of the river (Table 1), only *Carunculina parva* was found in abundance and only *Uniomerus tetralasmus* was recorded by Hinkley (1906). *Carunculina parva* was not reported in the early studies of the Mollusca of the Duck River in Tennessee (Ortmann, 1924) or the Cahaba River in Alabama (van der Schalie, 1938). These mussels are the smallest members of the Unionidae; our largest specimen measured 40 × 27 mm.

In addition to two species of fingernail clams from the family Pisidiidae (formerly Sphaeriidae), *Eupera cubensis* and *Sphaerium rhomboideum*, the profundal region also contained the Asiatic clam *Corbicula manilensis*. This is the first recorded sighting of *Corbicula* in the interior reservoirs of Mississippi. An occasional *S. rhomboideum* was found in the snag and debris area occupying the larger portion of the littoral zone. *Sphaerium rhomboideum* was the only bivalve found in any abundance in the reservoir. Representatives were most common in sampling areas 1, 2, and 6 (Fig. 1) in the deepest portion of the profundal zone. At the end of the study, their population densities ranged from 4 to 20 clams/m^2. The only species able to withstand the rigors of the fluctuating littoral zone was *Proptera purpurata;* a few were found in beach areas.

The largest numbers of individuals and diversity was found in the swift waters below the spillway. *Quadrula pustulosa, Proptera purpurata,* and *Lampsilis anodontoides* dominated the fauna. Of the 8 species found in the swift-flowing habitat, Hinkley (1906) recorded 6.

Summary

The habitat alterations in the Yalobusha River account, at least in part, for the absence of 13 species reported by Hinkley and the appearance of 9 other species new to this immediate area. Significant also is the complete absence of three other genera reported by Hinkley in 1906—*Obovaria, Plagiola,* and *Strophitus.* The restricted area below the spillway has created a habitat showing the most diversity and one more favorable to species that already occupied the river. Thus, we feel that habitat changes, especially impoundment and channelization of the Yalobusha River, have had a detrimental effect on the previously existing population of bivalve mollusks. Although some replacement fauna has occurred, the number of species has declined.

ACKNOWLEDGMENTS

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SEASONAL ABUNDANCE OF *AMNICOLA LIMOSA* (HYDROBIIDAE) EGGS AND INDIVIDUALS IN A RHODE ISLAND POND

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ABSTRACT

The seasonal abundance of Amnicola limosa *(Say) (Hydrobiidae) eggs was observed in Nonquit Pond, Rhode Island. Recruitment did not appear to be related to egg density.*

In the course of investigating periphyton colonization of glass slides, eggs of the prosobranch snail, *Amnicola limosa* (Say) were observed. The abundance of these eggs was measured at 40 cm and 1.0 m depths in Nonquit Pond, Rhode Island. The slides were exposed for three week periods with new slides being exposed every week. Only eggs containing embryos were counted.

Nonquit Pond is a shallow reservoir (mean depth 2.3 m) with stained, acidic water (pH 5.8-7.2) of low alkalinity (<5 mg $CaCO_3$/l). The littoral zone bottom ranges from small pebbles to boulders and there are few emergent macrophytes. Nonquit Pond is located in Newport County, Rhode Island.

The number of eggs/dm ^{2} are given in Figure 1. *Amnicola* eggs were first observed on May 20 in 1977 when the water temperature was 9° C. In 1978 they were first observed on May 4 at 14.5° C. The eggs were as Berry (1943) described them, being single, lenticular in shape with a thin laminated crest extending across the dorsal margin and amber in color. They were slightly smaller than those described by Berry, being 1.16 mm long and 0.80 mm wide at their base.

Maximum densities occurred in 1977 on July 14 at the shallow (40 cm) station and on June 28 at the deep (1.0 m) station. In 1978 maximum densities occurred on June 29 at the shallow station and on July 13 at the deep station. The highest density of unhatched eggs observed was 110 eggs/dm^2.

Eggs were last observed on August 3 and July 20 at the shallow and deep stations in 1977. In 1978 the last slides with eggs were collected on August 22 at both stations. Berry (1943) cites other works in which the spawning period of *Amnicola limosa* was given as April-August. Horst and Costa (1975) give data from D. R. Post's 1971 M.S. Thesis in which *Amnicola* egg

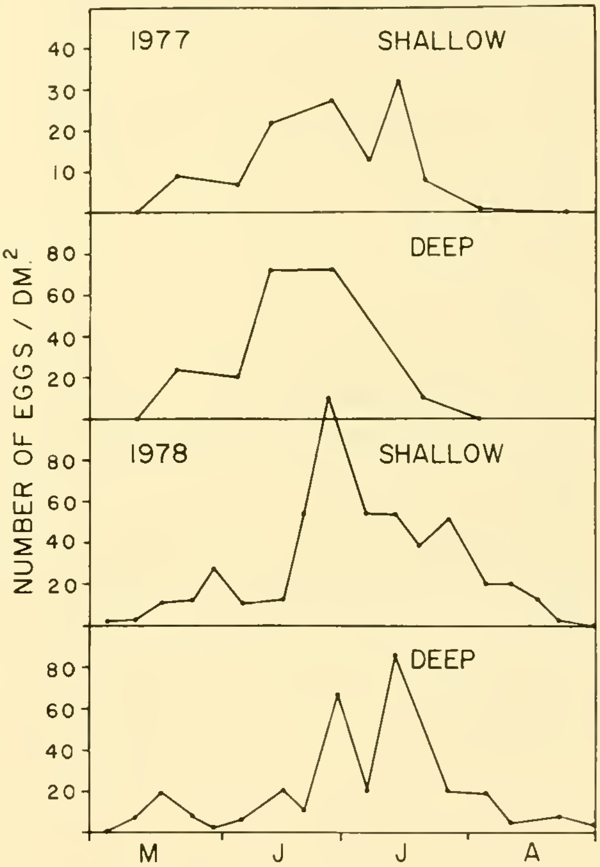

FIG. 1. Amnicola limosa *egg density (number/dm^2) collected on glass slides in Nonquit Pond, Rhode Island at 40 cm (shallow) and 1.0 m (deep) stations.*

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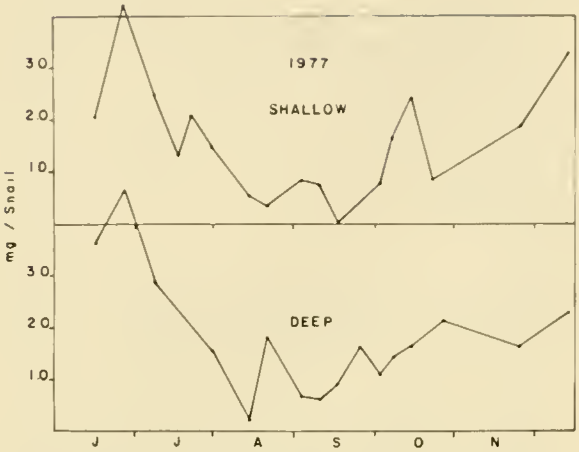

FIG. 2. Amnicola limosa *mean weight at 40 cm and 1.0 m in 1977 in Nonquit Pond, Rhode Island.*

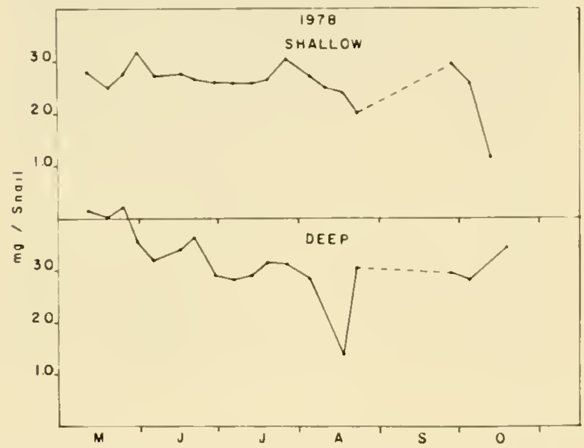

FIG. 3. Amnicola limosa *mean weight at 40 cm and 1.0 m in 1978 in Nonquit Pond, Rhode Island.*

production and breeding period appear consistent with the few published observations of this species.

The seasonal variation in egg numbers was similar in 1977 and 1978, although 1978 egg densities were higher at the shallow station. If egg density was tightly coupled with recruitment, and survivorship remained constant between years, there should have been more small snails in August 1978 than 1977. Snails were collected from the slide holder surfaces which provided a larger sampling area (350 cm² each) than the slides. The mean snail densities in 1978 and 1977 in August at the shallow station were 10.4 and 64.5 snails/dm², respectively, opposite the predicted trend based on egg densities. The densities at the deep station in 1978 and 1977 were 16.4 and 24.0 snails/dm², respectively. These densities were much higher than those reported by Horst and Costa (1975) for *Amnicola limosa* in McCargo Lake, New York.

The mean snail weights, an indication of the proportion of small snails on the slide holders, are given in Figures 2-3. The fairly constant mean snail weights in 1978 reflected the paucity of small snails collected. Conversely, in 1977 the mean snail weight clearly decreased as recruits entered the population. If samples from the slide holders are assumed to be equally biased between years, these data indicate a higher mortality following hatching in 1978. This period in their life history has been suggested by Hunter (1961) to be one in which snails suffer a high mortality rate.

It is hoped that these data will stimulate demographic investigations of *Amnicola limosa* populations. This species is capable of exerting an influence of periphyton species composition and standing crop (Kesler, 1979), yet its basic ecology, like many other freshwater snails is unknown.

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MORPHOLOGICAL NOTES ON *OREOHELIX AMARIRADIX* PILSBRY, 1934 (PULMONATA: OREOHELICIDAE)

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ABSTRACT

A population of Oreohelix amariradix *Pilsbry, 1934 was located near Lolo, Montana. The anatomy of the pallial region and the reproductive system is described. Comparisons are made between* O. amariradix *and the members of the* O. jugalis *complex.*

Bleached shells of *Oreohelix amariradix* were first collected by M. J. Elrod in the Bitterroot Mountains near Lolo, Montana. Elrod (1902) thought that these shells were a variety of *Pyramidula strigosa.* Shell specimens sent to H. A. Pilsbry were later described, tentatively, as a new species, *Oreohelix amariradix* (Pilsbry, 1934). The internal anatomy was not available to Pilsbry, thus the rank of species was not definite.

The type locality was given as follows: Bitterroot Mountains, along bluffs of Lolo Creek at 5000 feet, approximately 16 or 17 miles southwest of Missoula, Montana. Using data obtained from the collection of M. L. Walton, a small population of *Oreohelix amariradix* was located 4.5 miles west of Lolo, Montana (approximately 16 miles from Missoula) on the north side of U. S. Highway 12 and Lolo Creek. The locality, taken from a USGS topo map (Carlton Lake Quadrangle), is SW¼ of SE¼ of section 36 T12N R21W Missoula County, Montana, elevation approximately 3550 feet. Shell specimens have been sent to the Academy of Natural Sciences in Philadelphia, ANSP 347820.

The site is located on a grassy south facing slope overlooking Lolo Creek. The primary vegetation, other than bunch grasses *(Festuca* sp.), is composed of Ponderosa Pine *(Pinus ponderosa),* Service Berry *(Amelanchier canadensis),* and Nine Bark *(Physocarpus malvaceous).* The snails were found in small rock slides scattered along the face of the slope.

Specimens collected on 29 May 77 were compared with three topotypes obtained from the Academy of Natural Sciences in Philadelphia and also with the description of the type specimen (Pilsbry, 1934) (Table 1 and Figs. 1-6). Shell sculpture and shape were similar, with no discernible discrepancies. These comparisons plus the locality data lead to the conclusion that the specimens collected at the above locality are specimens of *Oreohelix amariradix.*

In March, 1978, three live specimens were

TABLE 1. *Shell measurements of* Oreohelix amariradix. *Measurements, in mm, are mean ± one std. dev. and the range.*

	Type	Topotypes (3)	Lolo, Mt. Specimens (21)
Diameter	14.5	11.9 ± 1.20	15.6 ± 1.47
		10.8 - 13.2	12.8 - 17.9
Height	8.5	7.3 ± 0.96	9.2 ± 1.13
		6.4 - 8.3	6.9 - 10.9
Height/Diameter	.5862	.6134 ± 0.02	.5881 ± 0.03
		.5926 - .6288	.5315 - .6450
Diameter of Umbilicus	-	3.7 ± 0.64	4.38 ± 0.49
		3.2 - 4.4	3.5 - 5.5
Diameter/Diameter of Umbilicus	~4.0	3.28 ± 0.25	3.58 ± 0.22
		3.0 - 3.47	3.22 - 4.26
Number of Whorls	5.33	5.0 ± 0.25	5.16 ± 0.21
		4.75 - 5.25	4.75 - 5.5
Embryonic Whorls	2.33	1.92 ± 0.29	2.0 ± 0.21
		1.75 - 2.25	1.75 - 2.25

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TABLE 2. *Measurements of reproductive systems (3) of* Oreohelix amariradix, *LF231-1, 2, and 3. Measurements, in mm, are the mean ± one std. dev., and the range.*

Penis (total length)	9.2 ± 0.67
	8.7 - 10.0
pustulose portion	4.0 ± 0.36
	3.7 - 4.4
ridged portion	5.3 ± 0.31
	5.0 - 5.6
Epiphallus length	3.8 ± 0.71
	3.0 - 4.4
Penial retractor length	6.5 ± 1.15
	5.4 - 7.7

FIGS. 1-6. **1**, **2**, and **3** *show a topotype of* Oreohelix amariradix *Pilsbry, 1934, ANSP 334291.* **4**, **5**, *and* **6** *show a specimen of* O. amariradix, *LF231-3, collected near Lolo, Montana.* × *2.*

drowned and then dissected for anatomical studies. No significant differences were found between these three specimens.

The pallial region (Fig. 7) has a well developed mantle gland without apparent vascularization from the pulmonary vein. The kidney is triangular, with its narrow end bent toward the

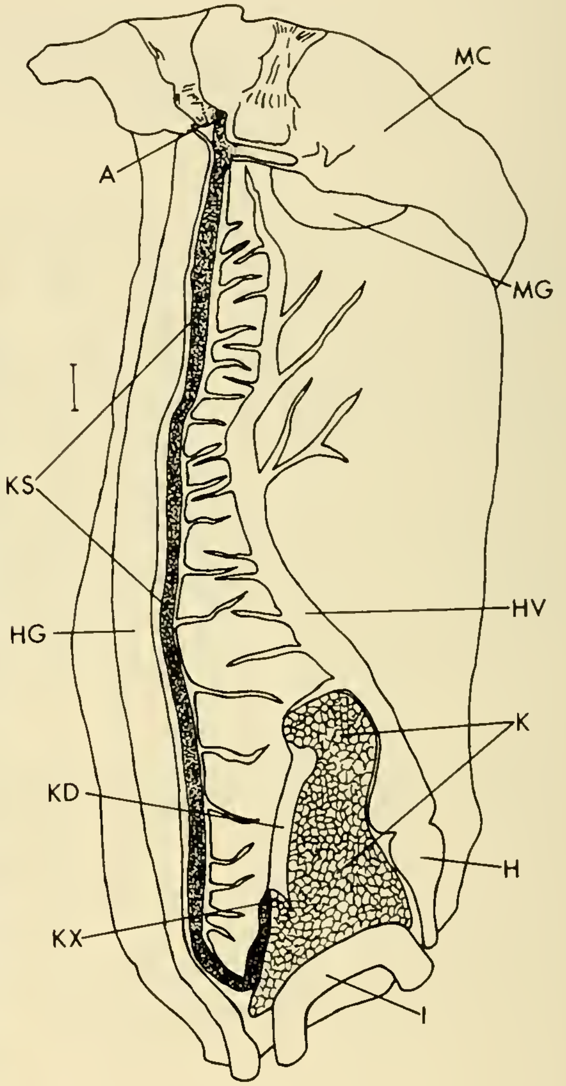

FIG. 7. *Pallial region of* Oreohelix amariradix, *LF231-3, collected near Lolo, Montana (camera lucida drawing). Scale line equals 1 mm. A = anus, H = heart, HG = hindgut, HV = pulmonary vein, I = intestine, K = kidney, KD = closed portion of ureter, KS = ureteric sulcus, KX = opening of closed portion of ureter, MC = mantle collar, MG = mantle gland.*

hindgut. The intestinal loop lies over the proximal margin of the kidney. The closed portion of the ureter begins in the curve formed by the bending of the narrow end of the kidney, and extends approximately two thirds of the length of the kidney. The long recurved ureteric sulcus is bordered by a renal ridge on the hindgut and an afferent vein. The heart is typical.

Data concerning the genitalia (Figs. 8 & 9 and Table 2) are as follows: The lobes of the ovotestis are angled to the shell axis, and the ovotestis duct is relatively tightly coiled. The talon, taken here to mean the receptaculum seminis and fecundation pouch of Bayne (1973), albumen gland, and prostate are typical. The spermatheca is moderately swollen at the base, the spermathecal duct is long and slender, and the head is ovoid and bound to the area just proximal of

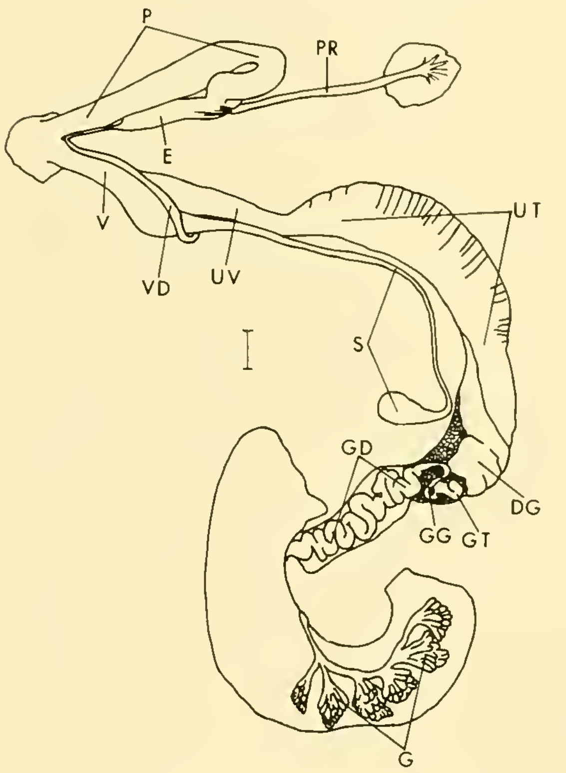

FIG. 8. *Genitalia of* Oreohelix amariradix, *LF231-3, collected near Lolo, Montana (camera lucida drawing). Scale line equals 1 mm. DG = prostate, E = epiphallus, G = ovotestis, GD = ovotestis duct, GT = talon, P = penis, PR = penial retractor muscle, S = spermatheca, UT = uterus, UV = free oviduct, V = vagina, VD = vas deferens.*

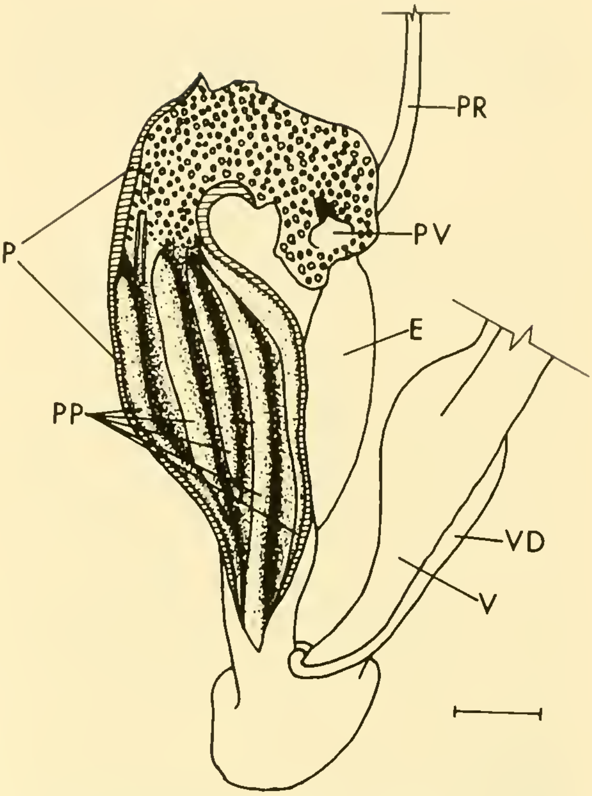

FIG. 9. *Penial chamber of* Oreohelix amariradix, *LF231-3, collected near Lolo, Montana (camera lucida drawing). Scale line equals 1 mm. E = epiphallus, P = penis, PP = penial pilasters, PR = penial retractor muscle, PV = penial verge, V = vagina, VD = vas deferens.*

the end of the uterus (spermoviduct of some authors) by connective tissue. The vagina is about equal in length to the free oviduct and has low ribbing internally. The vas deferens is bound by connective tissue to the peni-vaginal angle, and the expansion of the vas deferens into the epiphallus is abrupt. The epiphallus is considerably shorter than the penis (Table 2). The penial retractor muscle is inserted at the junction of the penis and the epiphallus. The penis is slender with the interior ridged portion more than half the total length of the penis (Table 2 and Fig. 9). The penial verge is prominent, with its opening at the tip of the verge.

The radula has 25-28 teeth per half row, and the central tooth is tricuspid.

Ten newborn *Oreohelix amariradix* were found in the terrarium in which the adults overwintered. The shells were transparent and ap-

peared to lack surface sculpture. Measurements of the shells produced the following data: Mean number of whorls = 2.18 (range 2-2.33), mean diameter = 3.12 mm (range 2.7-3.4).

DISCUSSION

Pilsbry (1939, p. 500) suggested that live specimens of *Oreohelix amariradix* and *O. jugalis* be compared. Solem (1975), in a discussion of the *O. jugalis* complex, gave both shell and anatomical data that can be compared to the data presented here.

The shell of *Oreohelix jugalis* (24 mm) is not only larger than that of *O. amariradix* (14.5 mm) but is different in proportions as well. The data for the genitalia also show significant differences. For example, *O. jugalis* has an epiphallus that is more than half the length of the penis, but in *O. amariradix* the length of the epiphallus is only 41% of the penial length (Table 2). Also, the penis of *O. jugalis* is shorter than that of *O. amariradix*. There are also ecological differences between these two taxa; *O. jugalis* is found in "large boulder piles or cliff base talus within the flood zone of the Salmon River" (Solem, 1975). *O. amariradix* is found in shallow talus on a south facing slope, a much drier and less sheltered habitat than that of *O. jugalis*.

According to Pilsbry (1939), *Oreohelix vortex*, *O. intersum*, and probably *O. junii* are members of the *jugalis* complex, thus comparisons of these species with *O. amariradix* seem pertinent.

The reproductive system of *Oreohelix vortex* has the pustulose portion of the penis much longer than the ridged portion (Solem, 1975). This is not true of *O. amariradix* (Table 2). In addition, the position of the penial verge opening is different in these two taxa.

The shell of *Oreohelix intersum* is markedly different from that of *O. amariradix* because of the radial striae found on the shell of *O. intersum*. In addition, the reproductive system of *O. intersum* is similar to that of *O. vortex* (see above).

It is clear that *Oreohelix amariradix* is distinct from *O. jugalis*, *O. vortex*, and *O. intersum*.

Comparisons between *Oreohelix amariradix* and *O. junii* show that *O. junii* has a shell that is larger, has a more depressed form, and appears smoother than the shell of *O. amariradix*. The reproductive systems are quite similar; the only notable differences are the folding of the vas deferens and the somewhat shorter epiphallus found in *O. junii*. The localities of these two taxa are approximately 275 miles apart and are ecologically different. These differences are probably sufficient to indicate that the two taxa are different species. Thus, Pilsbry's designation of *Oreohelix amariradix* as a species is confirmed.

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CALIBRATION OF AMINO ACID RACEMIZATION IN LATE PLEISTOCENE MOLLUSKS: RESULTS FROM MAGDALENA BAY, BAJA CALIFORNIA SUR, MEXICO, WITH DATING APPLICATIONS AND PALEOCLIMATIC IMPLICATIONS

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ABSTRACT

Amino acid enantiomeric (D/L) ratios in late Pleistoeene, marine mollusks from three uranium-series dated localities (Cayucos and the San Diego Nestor Terrace in California and the Magdalena Terrace in Baja California Sur) provide calibration points for establishing a 120,000-year isochron for interpolation of amino acid age estimates over a broad latitudinal range (35° N. to 24° N. lat.) of the California - Baja California continental borderland.

Leucine enantiomeric ratios in specimens of the bivalve Chione *from the Magdalena Terrace, compared with ratios predicted by a kinetic model for 120,000-year samples with constant (modern) diagenetic temperature, indicate slight paleotemperature reductions (1°-2° C.) at Magdalena Bay during late Pleistoeene glacial episodes in the northern hemisphere.*

There has long been a need to date more precisely Quaternary marine deposits in order to understand faunal composition and rates of tectonic deformation. Though uranium-series dating methods have been applied to such problems, significant uncertainties have been encountered when applied to mollusks, the most commonly found macroinvertebrates in mid-latitude terrace deposits (Kaufman, *et al.*, 1971; Szabo and Vedder, 1971; Ku and Kern, 1974). Consequently, other methods, particularly techniques suitable for mollusk dating, have been sought for those localities that lack corals, the most reliable organisms for uranium-series dating.

Amino acid racemization methods have been shown to serve as both a relative and semi-quantitative dating tool for Quaternary mollusks from both the Atlantic and Pacific coasts of the United States (Mitterer, 1974, 1975; Belknap, MS; Wehmiller, *et al.*, 1977, 1978; Kennedy, MS). It has been shown that enantiomeric ratios (*i.e.*, ratios of the D- and L-enantiomers of individual amino acids) increase with age in stratigraphic sequences of Pleistocene samples from the California continental borderland: Palos Verdes Hills (Mitterer and Hare, 1967), San Nicolas Island (Wehmiller, *et al.*, 1977), San Francisco Bay (Atwater, MS), the Los Angeles Basin (Wehmiller *et al.*, 1977), and the Ventura Basin (Wehmiller *et al.*, 1978). On the California coast well-established 120,000 to 125,000 year U-series dates on corals from Cayucos (35.3° N.) and the Nestor Terrace on Point Loma (32.7° N.) permit evaluation of latitude/temperature effects on racemization kinetics (Wehmiller, *et al.*, 1977; Wehmiller and Belknap, 1978). Amino acid data for localities with U-series absolute dates permit the evaluation of kinetic models of molluscan amino acid racemization (Wehmiller, *et al.*, 1977; Wehmiller and Belknap, 1978). These models require comparisons of estimated late Pleistocene temperature histories with available quantitative paleoclimatic data for glacial-age temperature reductions. Kinetic models are especially important for age estimation in cases where local interpolations between calibrated results cannot be made, owing to the lack of absolute dates for the intermediate localities.

In this paper we report amino acid data for a third uranium-series dated locality, at Magdalena

Bay, on the Pacific coast of Baja California Sur (24.6° N. latitude). The combined results presented here more than double the latitudinal range for which calibrated amino acid data can now be interpolated.

Localities, Samples, Analytical Results

Three samples of the venerid bivalve mollusk *Chione* cf. *C. undatella* (Sowerby, 1835) from the Magdalena Terrace, Magdalena Bay, (Figure 1, AMNH loc. F-6) Baja California Sur, have been analyzed for amino acid enantiomeric ratios. U-series coral analyses from this marine-cut terrace (Omura, *et al.*, 1979) indicate that this locality is approximately 120,000 (120 ka) yrs. in age and correlative with the early portion of isotopic Stage 5 (substage 5e of Shackleton and Opdyke, 1973). This particular time is well-represented by emergent terraces around the world (see Bloom, *et al.*, 1974, for example).

Amino acid analyses have been performed according to procedures described elsewhere (Wehmiller *et al.*, 1977; Kvenvolden, *et al.*, 1972; Frank *et al.*, 1977). Enantiomeric ratios have been determined by capillary column gas chromatography of the isopropyl-NTFA derivatives of the total amino acid mixture. The chromatographic method employs a 25 m glass capillary column similar to that used by Frank *et al.* (1977) and marketed under the name Chirasil-Val (Applied Science Laboratories, State College, PA). Column conditions were as follows: He carrier, 12.0 psi; program isothermal at 90° C. for 16′, 1°/min. to 135° C., 32′ isothermal. A representative chromatogram is shown in Figure 2. This analytical method represents an alternative to the (+)-2–butyl–NTFA method used for most previous gas chromatographic studies of fossil amino acid enantiomeric ratios (Kvenvolden, *et al.*, 1972, 1973; Wehmiller, *et al.*, 1977). Comparison of the two methods shows a good agreement (within 2 to 5%) for most amino acids (Wehmiller, unpublished).[1]

FIG. 1. *Index map of the Magdalena Bay-Almejas Bay area of Baja California Sur, Mexico, showing fossil localities (AMNH locs. F-5 to F-8) in the late Pleistocene Magdalena Terrace described by Omura,* et al., *(1979). U-series dated specimens (corals and echinoids, Omura* et al., *1979) and amino acid enantiomeric dated specimens* Chione) *form coexisting samples collected at locality F-6. AMNH Loc. F-6, about 1.5 km north of the village of Puerto Magdalena (24°38′N., 112°09′W.), Santa Magdalena peninsula, Baja California Sur; fossils collected by W. K. Emerson, March 17, 1957 (= California Academy of Sciences locality 754; see Jordan, 1936.*

Enantiomeric ratios for six amino acids for samples from Magdalena Bay are given in Table 1. The data represent mean values of peak-height determinations from at least two chromatograms for each sample. The results (Table 1) demonstrate good reproducibility and are consistent with relative intrageneric racemization rates in comparison with previous observations (Wehmiller, *et al.*, 1977; Lajoie, *et al.*, in press), thereby meeting the two available criteria for data reliability.

DISCUSSION

For purposes of discussion, results for only one amino acid, leucine, are considered here. Kinetic models for leucine racemization have been most

[1] Current work at the University of Delaware on the comparison of these two analytical methods indicates the following relationship for leucine:

D/L leucine (Butanol) = 1.029 [D/L leucine (isopropanol)] + 0.014

r = .993, n = 48 samples (of 5 genera)

These comparisons have been made by splitting a single sample hydrolyzate, after all desalting steps, into two aliquots for esterifation with either the (+)-2–butanol or the isopropanol.

The only amino acid for which significant deviations between the two methods are observed is phenylalanine: D/L values determined by the isopropanol method are about 15-20% less than those determined by the (+)-2–butanol method.

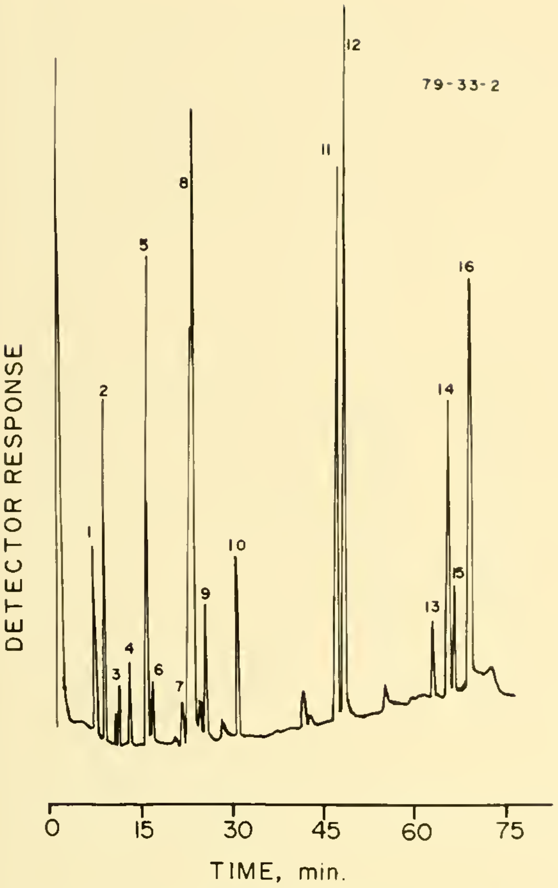

FIG. 2. *Chromatogram of isopropyl-NTFA derivatives of amino acids in* Chione. *(Magdalena Terrace Sample 79-33-2) on 25 m Chirasil-val optically active column. Peak identification as follows: 1, 2, D, L alanine; 3, 4, D, L valine; 6, D-alloisoleucine; 7, L-isoleucine; 8, D + L proline; 9, 10 D, L leucine; 11, 12, D, L aspartic acid; 13, 15 D, L phenylalanine; 14, 16, D, L glutamic acid. Program: 90°, 16′ isothermal; 1°/min. to 135°; 32′ isothermal. He carrier gas pressure, 12 psi.*

thoroughly evaluated (Wehmiller and Belknap, 1978), though such models can easily be developed for other amino acids using observations of intrageneric relative racemization rates (Lajoie, *et al.*, in press).

In Figure 3, the leucine data for the Magdalena Bay *Chione* are compared with leucine data in the venerid bivalve *Protothaca* from the Cayucos and Nestor Terrace calibration localities in central and southern California. Available evidence indicates that *Protothaca* and *Chione* have leucine racemization kinetics that are identical within analytical uncertainties (Lajoie, *et al.*, in press). The leucine data are plotted vs. present mean annual air temperatures at each locality, in order to demonstrate the latitude/temperature effect on enantiomeric ratios in samples of similar age. Plots of enantiomeric ratios against latitude would have similar appearance (Wehmiller, *et al.*, 1977; Kennedy, MS). Also shown in Figure 3 are the leucine D/L curves predicted by the kinetic model of Wehmiller and Belknap (1978) for samples with ages of 80, 120, and 200 ka, for effective ground temperatures that would be associated with the present mean annual air temperatures shown on the abscissa of Figure 3. Implicit in these model isochrons are assumptions about the temperature dependence of the racemization reaction and, more importantly, about the relation between ground and air temperatures at coastal localities. For purposes of construction of model isochrons, it has been assumed that these ground-air temperature relationships are constant over latitude and through time (Wehmiller, *et al.*, 1977). Mean annual air temperatures are used in Figure 3 because these data are more easily obtained than ground temperature, though the actual ground temperature at any site might be a few degrees warmer (see Wehmiller, *et al.*, 1977: 13-17, 52-54,

TABLE 1. *Amino acid enantiomeric (D/L) ratios* in* Chione *samples from Magdalena Bay, Baja California Sur, Mexico. All specimens from AMNH locality F-6; sample numbers 79-33-2 and 79-33-2A from two articulated valves of the same specimen.*

	AMINO ACID[1]							
Sample No.	LEU	GLU	VAL	ALA	PHE	ASP	ILEU	% Calcite
79-33-1	.70	.60	.58	.98	.74	.75	n.m.[2]	< .4
79-33-2	.72	.65	.64	1.03	.79	.78	1.04	< 1.0
79-33-2A	.70	.61	.62	1.06	.68	.75	.98	< 1.0

[1] Amino acid abbreviations:

LEU	Leucine	PHE	Phenylalanine
GLU	Glutamic acid	ASP	Aspartic acid
VAL	Valine	ILEU	Isoleucine (D-alloisoleucine/ L-isoleucine)
ALA	Alanine		

[2] n.m. not measured

* Ratios are averages of peak height ratios determined from at least two chromatograms of each sample. Precision of multiple determinations is between 2% and 6%, depending on amino acid.

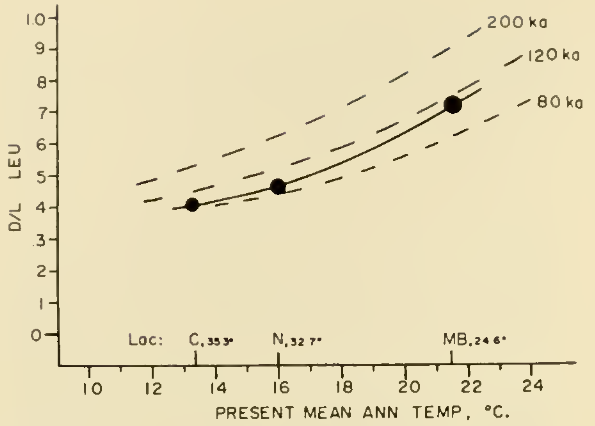

FIG. 3. *Plot of D/L leucine vs. mean annual air temperature and latitude for three U-series dated (ca. 120 ka) calibration localities: C, Cayucos; N, Nestor Terrace; MB, Magdalena Bay. Data for Cayucos and Nestor Terrace are on* Protothaca *(Wehmiller,* et al., *1977). Data for Magdalena Bay are on* Chione, *a genus thought to have racemization kinetics identical with those of* Protothaca *(Lajoie,* et al., *in press). Leucine data for* Chione *have been factored upward by about 3% (see equation in text) for direct comparison of different analytical methods employed for these results. Temperature data from summary in Wehmiller,* et al., *(1977) and Hastings (1964). Size of data points represents ± 5%, the typical uncertainty expected for multiple analyses at a single locality (see Wehmiller* et al., *1977: Table 5).*

Solid line represents the U-series calibrated isochron, fixed to actual analytical results and assigned an age of 120 ka. Dashed lines represent model isochrons, drawn from the kinetic model of Wehmiller and Belknap (1978) for constant effective temperatures as indicated. The separation between the model and actual isochrons for 120 ka is interpreted as the kinetic consequence of late Pleistocene temperature reductions, which would have slowed the racemization reaction and lowered the effective temperature for Pleistocene samples compared with modern samples.

Table 2; Wehmiller, 1977). Uncertainties in ground-air temperature relations are probably minor for comparison of marine terrace amino acid data from closely-spaced localities, but these uncertainties become more important when considering results (such as those presented here) for samples from a broad latitudinal range.

The solid line in Figure 3 represents the 120,000 year U-series calibrated isochron. No assumptions regarding kinetic models are needed to interpret data that fall on this isochron, if it is assumed that samples in this latitudinal range have been exposed to similar fluctuations in paleotemperature during late Pleistocene climatic cycles.

The divergence between the 120 ka kinetic model curve and the actual calibrated curve demonstrates the effect of late Pleistocene temperature reductions on the racemization process (Wehmiller and Belknap, 1978). For example, the Nestor Terrace data plot about 0.06 lower than would be predicted by the kinetic model if these samples had always been exposed to constant (modern) effective temperatures (those associated with the present mean annual air temperature of 16° C.). The Nestor (32.7° N.) data would fall on the model 120 ka isochron for an effective Pleistocene temperature of about 13.5° C.; the 2.5° C. difference between the effective Pleistocene temperature and the present effective temperature is considered to be the kinetic effect of full-glacial temperature (air and/or ground) reductions of about 5° C. The timing of these paleotemperature reductions is based on the glacial minima-maxima model of Shackleton and Opdyke (1973). For a given locality, the full glacial temperature reduction would always be greater than the effective Pleistocene temperature reduction, because the latter represents the average kinetic effect of all temperatures to which the sample has been exposed during its fossil history. A full discussion of the optional temperature histories that would be consistent with this effective temperature reduction is found in Wehmiller, *et al.* (1977, 61-66). The Cayucos (35.3° N.) data suggest a similar temperature reduction; the parellelism of the calibrated and the model isochrons between 36° N. and 32° N. indicates that reductions in effective temperature (and possibly, therefore, of temperature itself) have been similar over this latitudinal range during the past 120,000 years.

The Magdalena Terrace (24.6° N.) data lie much closer to the 120 ka model isochron than do the Cayucos and Nestor data, and indicate effective paleotemperature reductions were about 1.0° C., representing full glacial temperature reductions of no more than 2.0° C. The convergence of U-series calibrated isochron and the model isochron at more southerly latitudes indicates that greater paleotemperature reductions have occurred in southern California than in southern Baja California. Though the magnitude of this change in the paleotemperature gradient can be only qualitatively estimated because of the broad

latitudinal range over which the model isochrons (with their assumptions of constant ground-air temperature relations) are being extrapolated, the paleotemperature estimates derived from Figure 3 are reasonable in comparison with paleoclimatic information for both coastal and nearshore marine environments between 36° and 24° N. latitude (CLIMAP, 1976; Peterson, *et al.*, 1979).

CONCLUSIONS

Amino acid enantiomeric ratios in mollusks from three U-series dated marine terrace sites between 36° and 24° N. latitude on the Pacific coast provide a calibrated isochron for samples approximately 120,000 years in age over a wide range of modern mean annual temperatures (approximately 9° C.). The availability of this isochron should aid in the dating of late Pleistocene terrace localities at intermediate latitudes by interpolation of data between calibration points.

Comparison of the U-series calibrated isochron with kinetic model isochrons indicates that greater paleotemperature reductions have occurred in coastal California than in southern Baja California during some part of the past 120,000 years, probably during times of maximum glacial advance. The consistency of the Magdalena Bay results with independent paleoclimatic information supports the kinetic models that are in use for the quantification of age/temperature relationships of amino acid racemization data in Quaternary mollusks from Pacific coast marine terraces.

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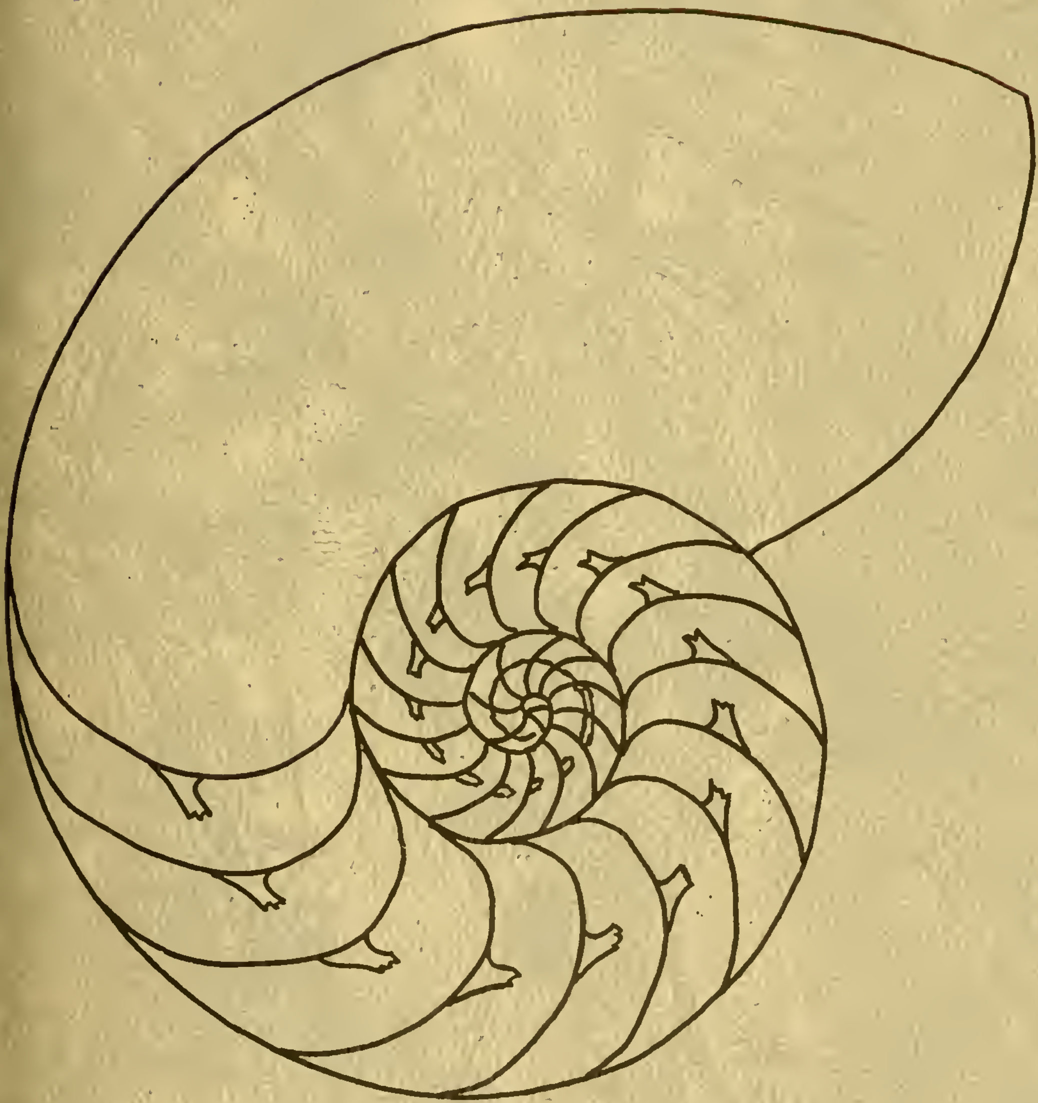

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PUBLICATIONS RECEIVED

Evolutionary Systematics of Bivalve Molluscs (edited by C. M. Yonge and T. E. Thompson). 1978. Philos. Trans. Royal Soc. London, sect. B, vol. 284, pp. 199-436. 18 papers of major significance in the systematics, evolution and paleontology of the Bivalvia by leading malacologists.

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Venus, The Japanese Journal of Malacology. Special Publication, 1979, Tokyo. Check List of New Genera and Species and Author Index to vols. 1-36 (50 years). A very useful and necessary index to about 1000 new molluscan names proposed in this well-known journal. Crucial dates of publication are given for 36 volumes.

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Pathways in Malacology. 1979. 295 pp. Edited by S. van der Spoel, A. C. van Bruggen, J. Lever. Eleven chapters, on somewhat unrelated subjects, representing papers given at the Sixth Congress of the Unitas Malacologica Europaea in Amsterdam in 1977. Some of the papers are excellent and stimulating, such as J. Lever's "On Torsion in Gastropods", "Cementation in the Bivalvia" by C. M. Yonge, "A Theory of Land Snail Biogeographic Patterns Through Time" by Alan Solem, and Furnestin's intriguing "Planktonic Molluscs as Hydrological and Ecological Indicators". Knudsen's "Deep-sea Bivalves" is an excellent, up-dated review. Bohn, Scheltema and Holkema, Utrecht. Bound, $72.00. An expensive way to publish a transient, albeit valuable, symposium.

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REPRODUCTIVE CYCLE PATTERNS IN THE CHITON GENUS *MOPALIA* (POLYPLACOPHORA)

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ABSTRACT

The reproductive cycles of the five most common species of the chiton genus Mopalia *on the British Columbia coast are examined in three locations in relation to environmental factors over a 3 to 4 year period. A diversity of patterns is evident.* Mopalia ciliata *starts gonadal growth in the summer, while* Mopalia laevior *starts gonadal growth in the autumn. Both patterns occur in different populations of* Mopalia hindsii. *Photoperiod and temperatute may act as environmental cues in controlling these patterns. Spawning in* M. hindsii *usually occurs during the period when temperatures are near minimal, or just starting to rise, while* M. ciliata *and* M. laevior *spawn in synchrony with the spring phytoplankton bloom.* Mopalia lignosa *has a more irregular reproductive cycle, and gonadal growth may follow spawning in the late winter and spring, as well as summer spawning activity. There are no obvious factors correlated with these periods of gonadal growth and spawning. The most irregular reproductive pattern occurs in* Mopalia muscosa *and animals in mature and spent condition are found throughout the year. This may be an adaptation to life in the intertidal zone, where favourable conditions for gamete production and spawning may be determined more by microhabitat conditions than by general hydrographic and climatic factors.*

INTRODUCTION

Members of the North Pacific genus *Mopalia* are a characteristic part of the inter- and subtidal faunas along the west coast of North America, but little attention has been given to their reproductive biology and general ecology. In the present study, the reproductive cycles of the five most common species in British Columbia are examined. These species are *Mopalia hindsii* (Reeve, 1847), *Mopalia ciliata* (Sowerby, 1840), *Mopalia laevior* (Pilsbry, 1918), *Mopalia lignosa* (Gould, 1846) and *Mopalia muscosa* (Gould, 1846). All previous studies on this genus were conducted in California. Barnawell (1954) observed the gonadal condition of animals of three species in San Francisco Bay over a period of a year, and Thorpe (1962) presented a list of times when he observed individuals spawning for eight species over a six year period. Studies using the gonadal index method were made by Giese *et al.* (1959) on *M. hindsii* in Monterey Bay, and by Boolootian (1964) and Monroe and Boolootian (1965) on *M. muscosa* in Santa Monica Bay. These reports do not give a clear understanding of the reproductive cycles of the various species. In the present study, observations were made on reproductive cycles and on environmental conditions in three locations over a 3 to 4 year period, in order to determine the extent to which there has been a separation in the timing of reproductive events in these closely related species, and to elucidate possible factors controlling the reproductive cycles.

The most northerly ranging of the species in the present study is *Mopalia ciliata*, which is known from Unalaska Island in the Aleutians (Dall, 1921; *M. wosnessenkii = M. ciliata)* to Bahia Totos Santos, Baja California (Berry, 1922), and *Mopalia muscosa*, which is known from the Shumagin Islands on the Alaskan Peninsula (Dall, 1878; *M. ciliata = M. muscosa)* to Isla Cedros, Bahia California (Berry, 1922). The other

species range from southern Alaska southward. *Mopalia hindsii* is the most southerly ranging species, being reported from Sitka, Alaska, to the Gulf of California (Dall, 1921). *Mopalia lignosa* is known from Sitka to Bahia Magdalena, Baja California (Dall, 1921). *Mopalia laevior* has a more restricted range, being reported only from Sitka (Burghardt and Burghardt, 1969) to its type locality at Olympia, Puget Sound (Pilsbry, 1918), and more recently to central California (Rice, 1971).

On the British Columbia coast the different species vary in their vertical distributions (Himmelman, unpublished). *Mopalia muscosa* is an intertidal species and occurs in greatest numbers in the mid-intertidal region. *Mopalia hindsii* and *Mopalia ciliata* are common in the subtidal community, as well as in the low intertidal zone, up to the level of about 2 m above lowest water of spring tides (LWST). *M. ciliata* is more often found in tight crevices and under rubble than *M. hindsii*, and in the intertidal area both species are most common on vertical faces and undercuts. In contrast to the above species, *Mopalia laevior* is a subtidal species and rarely occurs above LWST. *Mopalia lignosa* is most common at shallow depths in the subtidal zone, and in the intertidal zone it can occur up to as high as 3 m above LWST. It can be very common intertidally in some quiet water places where there is much organic debris (I. M. Cowan, *personal communication*).

STUDY AREAS AND METHODS

Most of the observations in the present study were made at three locations in British Columbia: in subtidal communities at First Narrows in Vancouver and at Porteau in Howe Sound, and in an intertidal community at Botanical Beach, on the outer coast of Vancouver Island (Fig. 1). A few collections were also made at Eagle Harbour, 11 km from First Narrows. Not all five species of *Mopalia* were present in sufficient quantities for regular collections at each site, and thus were collected only where it was feasible to make subsequent collections. I tried to collect 10 or more adult animals of each species on each collection date, but this was often not possible for the rarer species.

The gonadal index, defined as the percentage wet weight of the gonad to total live body weight, was determined for each animal, this providing a

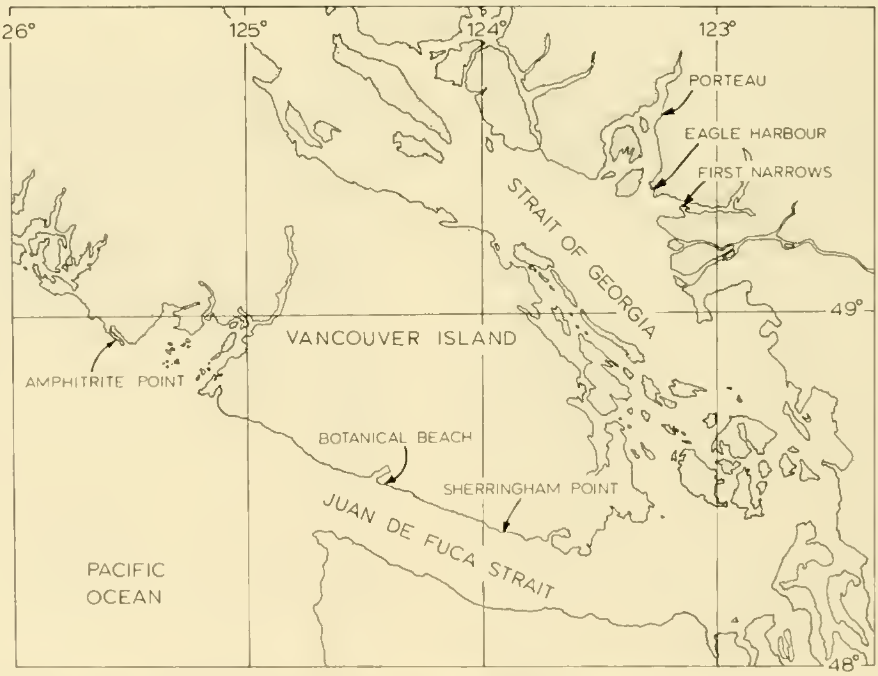

FIG. 1. *Southwestern British Columbia, showing where the animals and environmental data were collected.*

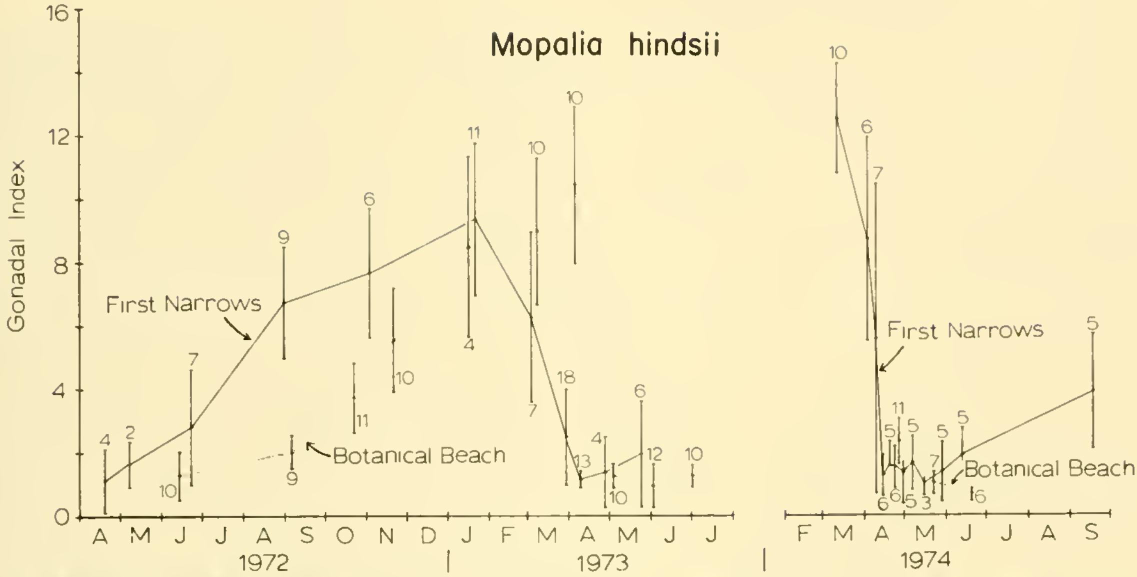

FIG. 2. Mopalia hindsii. *Mean gonadal index and 95% confidence limits for animals at First Narrows and Botanical Beach. The number associated with each bar is the sample size.*

quantitative value for its reproductive condition. In the process of determining the gonadal index, I made a standard practice of returning the animals to fresh sea water after allowing them to dry on paper towelling for 15 min for weighing purposes. When spawning was imminent in the field, this procedure sometimes induced spawning. A record was kept of animals which spawned in this manner. The weight range of the animals used for plots of the mean gonadal index against time was 10-35 g for *Mopalia hindsii*, 4-20 g for *M. ciliata*, 8-35 g for *M. laevior*, 4-19 g for *M. lignosa*, and 10-50 g for *M. muscosa*. Gonadal indices within these ranges are relatively independent of animal size (Himmelman, 1976).

To examine the relationship between temperature and reproductive events, for the population at First Narrows I used measurements of incoming water at the Vancouver Public Aquarium. The intake was located 1 km from and at about the same depth as the collection site, and provides a good record of the conditions to which the animals were exposed (a graph of these data is presented by Himmelman, 1976). For the populations at Botanical Beach, I interpolated values from daily surface temperature measurements taken at lighthouses at Sherringham and Amphitrite Points (Fig. 1; Hollister, 1971, 1972, 1974, Giovando and Hollister, 1974; Giovando, *Personal communication*.). A good record of temperatures at Porteau during the spawning period in 1973 was made with a thermograph at the collection site.

RESULTS AND DISCUSSION

Reproductive Cycles

Mopalia hindsii. A distinctly annual reproductive cycle was seen in both locations where *M. hindsii* was studied. At Botanical Beach, spawning was completed by mid-June 1972, since every animal collected at this time had small gonads containing few or no gametes (Fig. 2). During the following summer, there was little gonadal enlargement, but after September the gonads grew rapidly to a peak in early April 1973. In 1973, there was a complete spawning during April and all animals collected in May, June and July 1973 had depleted gonads. In 1974, only four collections were made. On 27 April, the animals collected had partly spawned or spent gonads, suggesting that spawning was near completion, and all animals collected in May and June were in spent condition.

At First Narrows, animals in the first collection in April 1972 had completed spawning (Fig. 2). Gonadal growth commenced in the spring and by late August the gonads were two-thirds macimum size. This was in marked contrast to the

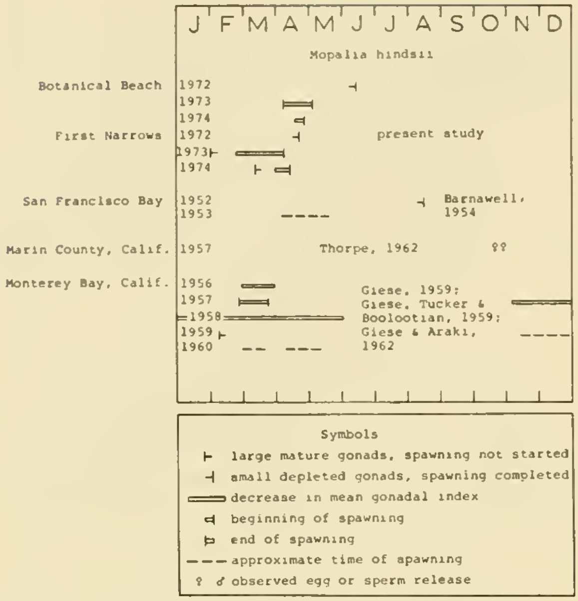

FIG. 3. Mopalia hindsii. *Summary of spawning observations.*

events at Botanical Beach, where gonadal growth did not start until autumn. At First Narrows, gonadal growth during the autumn and winter was slower and a peak was reached in January 1973. Spawning at First Narrows in 1973 was a slow process, lasting 2-3 months, in contrast to the one month spawning at Botanical Beach in that year. It was underway in early March, when one spent animal and six with intermediate-sized gonads were collected, and all animals did not have spent gonads until 10 April. In 1974, *M. hindsii* had an abrupt spawning at First Narrows. A few partly spawned animals were first collected on 4 April and spawning was completed on 15 April. Gonadal growth during the summer was again evident at First Narrows in 1974.

A list of spawning observations for *M. hindsii* from the present and earlier studies is shown in Figure 3. Barnawell (1954) observed a reproductive cycle in *M. hindsii* in San Francisco Bay similar to that observed in my study. There was a progressive increase in the proportion of animals with large gonads from late August to November 1952, and the majority of the animals collected from January to April 1953 had large gonads. Subsequently, spawning occurred, since most animals collected in May had small gonads. Egg release by *M. hindsii* from two locations in Marin County, California, was seen during late October by Thorpe (1962). In Monterey Bay, *M. hindsii* showed gonadal growth starting in the autumn in 1956, 1957 and 1958, and there was a well defined spawning in March in 1956 and 1957, but not in the following three years (Giese, 1959; Giese *et al.*, 1959, Giese and Araki, 1962). A gradual decline in the mean gonadal index occurred from November 1957 to July 1958, and three breeding periods were reported between November 1959 and late spring 1960.

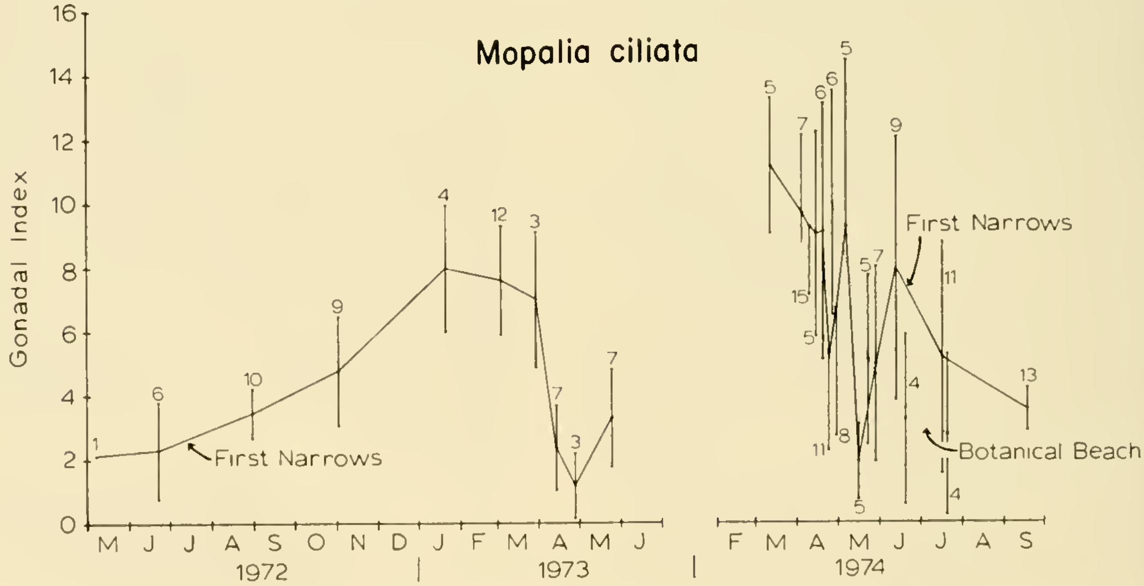

FIG. 4. Mopalia ciliata. *Mean gonadal index and 95% confidence limits for animals at First Narrows and Botanical Beach.*

In summary, *Mopalia hindsii* shows gonadal growth starting in the summer in the subtidal population at First Narrows, and starting in the autumn in intertidal populations at Botanical Beach and Monterey Bay. There is usually spawning in March or April, but in California in some years there may be spawning activity from early winter to late spring.

Mopalia ciliata. The reproductive cycle of *M. ciliata* was studied in greatest detail at First Narrows (Fig. 4). The data from 1972 and 1973 showed a regular cycle, even though only a few animals were found on some collection dates. Gonadal enlargement in 1972 proceeded gradually after June and reached a peak in January 1973. All animals collected in March 1973 had mature gonads, and one male in each of the two March collections discharged some sperm, suggesting that spawning was imminent. The gonadal indices dropped abruptly in early April 1973 and every animal from the 14 April collection had depleted gonads.

In 1974, there may have been some summer spawning following the main spring spawning. All animals collected on 20 April and earlier had mature gonads, and one-half of the animals collected on 24 April had spent gonads. It was unexpected to find four of five animals from 7 May with large mature gonads. Possibly spawning was delayed in some localized areas at First Narrows, and the variation in the data was due to sampling error. Most of the animals collected in June and July had mature gonadal tissues, but many of these animals had small- to intermediate- sized gonads. By 18 September, 10 of the 13 animals collected had spent gonads.

On 20 April 1971, two *M. ciliata* with depleted gonads were collected at First Narrows. On the assumption that this species is mature during the winter, as in 1972 and 1973, spawning in 1971 probably occurred in March or April.

At Eagle Harbour, two collections of *M. ciliata* were made near the time of the 1973 spawning season. The mean gonadal index decreased from 11.8 ± 1.9 (95% confidence interval, n = 10) on 23 March to 10.2±2.8 (n = 9) on 4 April, and all animals in both samples contained large quantities of gametes. Here, spawning may have occurred at about the same time as at First Narrows.

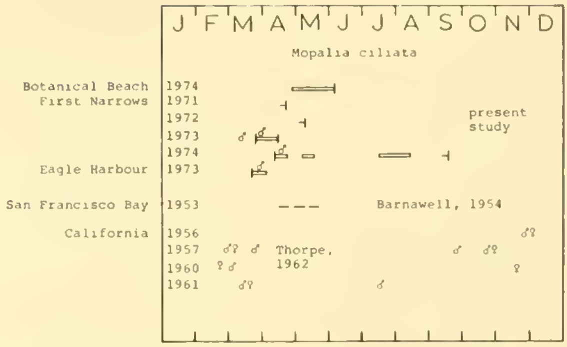

FIG. 5. Mopalia ciliata. *Summary of spawning observations.*

At Botanical Beach, four collections of *M. ciliata* were made in 1974 (Fig. 4). On 27 April, all animals collected had large mature gonads. The mean gonadal index dropped abruptly during May and all animals from June and July were in spent condition.

A summary of spawning observations for *Mopalia ciliata* is shown in Figure 5. In British Columbia spawning occurred from late March through May, except at First Narrows in 1974, when there was some delayed spawning activity. In San Francisco Bay, Barnawell (1954) reported that animals with large gonads were found in all seasons, but his data show a decrease in the proportion of animals with large gonads from April to July, which suggests there was spawning activity during this period. From various locations in California, Thorpe (1962) reported 20 observations of individuals spawning: 12 were in the period 21 February to 21 March, one was from 15 July, and seven were in the period 25 September to 20 November.

Thus, *Mopalia ciliata* spawns from late winter through spring in British Columbia, but in the southern part of its range it may also spawn in the summer and autumn. The timing of gonadal growth is only known for First Narrows, where it starts in the summer.

Mopalia laevior. This species was only examined in the subtidal populations at Porteau and First Narrows (Fig. 6). At Porteau, spawning was in progress, but near completion, when the first collection was made on 8 April 1971. The mean gonadal index was low, but four animals released gametes in the laboratory. In 1972, spawning was delayed, since all animals collected on 7 April, with the exception of one partly

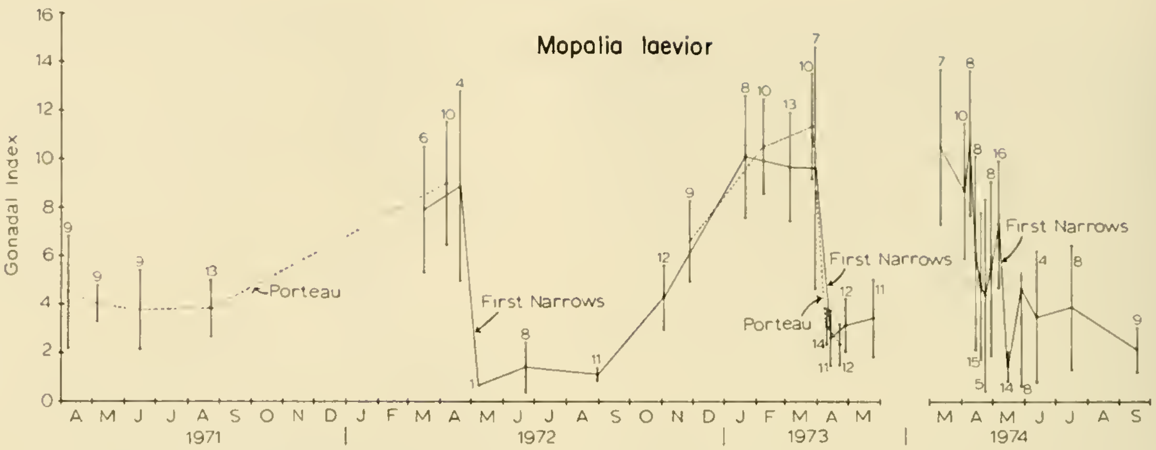

FIG. 6. Mopalia laevior. *Mean gonadal index and 95% confidence limits for animals at First Narrows and Porteau.*

spawned male, had large gonads. There was an abrupt spawning at Porteau in 1973. On 27 March only one spent animal was collected, and on 10 April all animals had nearly completed spawning.

At First Narrows, there was no indication of spawning in collections from March and April 1972, but one animal collected on 8 May was in spent condition, as were all animals collected in June and August (Fig. 6). The gonads enlarged rapidly during the autumn of 1972 and reached peak size by late January 1973. One animal with a small gonad was found on 6 March and another on 30 March. In the latter collection, four animals spawned in response to being dried and rewetted. There was an abrupt spawning in early April 1973, and only small quantities of gametes or none at all were seen in animals collected on 14 April. As in *M. ciliata*, the spawning period of *M. laevior* at First Narrows in 1974 was poorly defined. The most striking drop in the mean gonadal index was during 10-24 April, but the data were erratic and a high proportion of unspawned animals was later collected on 30 April and 7 May. Animals collected on different dates, and probably from slightly varied localities, differed in the extent to which they had spawned, suggesting that the population at First Narrows did not spawn in synchrony in 1974. All animals from the 18 September 1974 collection had spent gonads.

One collection of *M. laevior* was made at Eagle Harbour on 4 April 1973. The mean gonadal index was 1.4±0.7 (n=5) and all animals had depleted gonads.

In summary, *Mopalia laevior* has a distinctly annual reproductive cycle, with gonadal growth starting in the autumn and usually an abrupt spawning in the spring (Fig. 7). At First Narrows, spawning always occurs in synchrony with spawning in *M. ciliata*. There are no data on reproductive events in *M. laevior* in the literature.

Mopalia lignosa. At Porteau, *M. lignosa* appeared to spawn twice in 1971 (Fig. 8). Spawning was imminent on 8 April, when all animals had large mature gonads and four males spawned in the laboratory. One month later, seven of the 10 animals collected had intermediate- to small-sized gonads. Subsequently some gonadal growth occurred, and there was additional spawning activity sometime between mid-June and late-August. In 1972, one collection of four animals was made on 7 April. Three males had gonadal indices of 15.3-19.5 and one female had an index of 7.5. These four animals appeared mature, but could not be induced to spawn in the laboratory. In

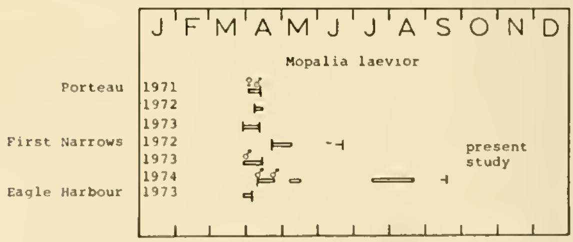

FIG. 7. Mopalia laevior. *Summary of spawning observations.*

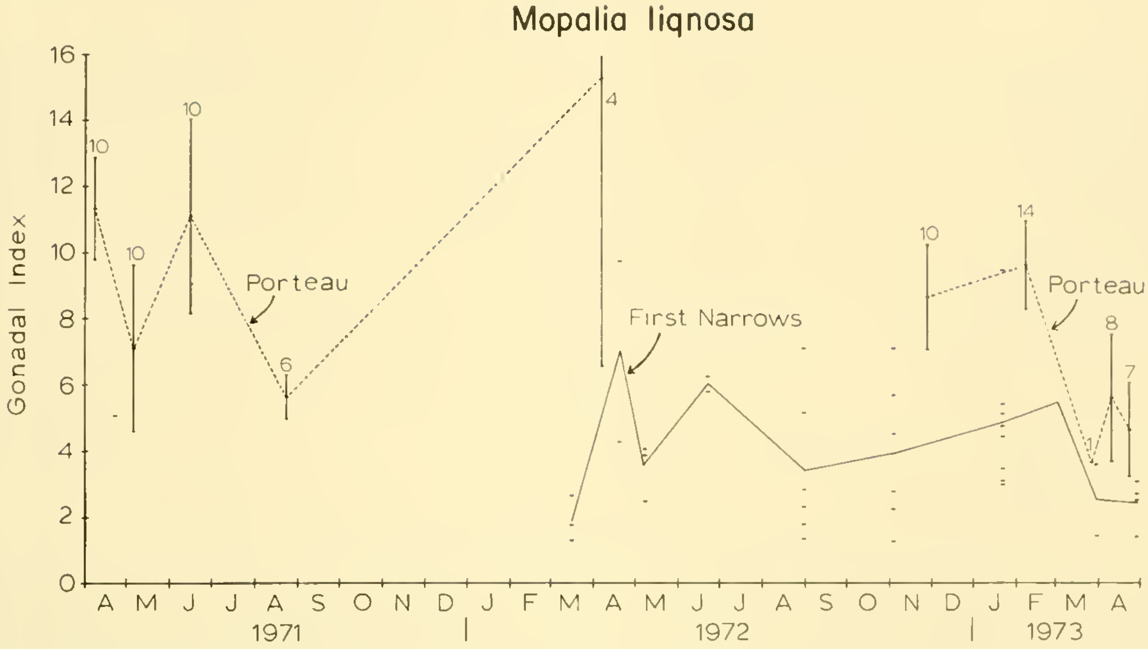

FIG. 8. Mopalia lignosa. *Mean gonadal index and 95% confidence limits for animals at Porteau, and gonadal index value for each animal collected at First Narrows.*

1973, animals with mature gonads were found in February, and spawning occurred sometime prior to 10 April, when the eight animals collected contained only small quantities of gametes. The one animal collected on 27 March 1973 was in spent condition.

Interpretation of the reproductive cycle of *M. lignosa* at First Narrows was complicated by both the small size of many of the samples and the irregular sequence of events (Fig. 8). In 1971, spawning may have occurred in April, since one animal from 20 April released sperm in the laboratory. In 1972, three spent animals were found in March. Animals with larger gonads were found in April through June and some spawning may have occurred in the summer, since in August the animals collected contained smaller quantities of gametes. There was no evidence of spawning in November 1972 and January 1973, but by late April 1973, the gonads were notably smaller and contained only traces of gametes.

There are few data on spawning of *M. lignosa* in the literature (Fig. 9). On the open coast near San Francisco Bay, Thorpe (1962) observed spawning by five animals between 27 February and 13 March 1957. In a study during April and May 1974, Watanabe and Cox (1975) induced some animals to spawn in the laboratory by keeping them in stale water. They were unable to induce spawning by numerous other methods.

In summary, reproductive events in *Mopalia lignosa* follow a less regular pattern than in *M. hindsii*, *M. ciliata* and *M. laevior*. There can be spawning during late winter, spring and summer, and gonadal growth may occur in the spring as well as in the winter.

Mopalia muscosa. Midway in the study of *M. muscosa*, I realized that the reproductive condition of animals varied greatly in different pools at any one time. Since animals from different pools on the same collection dates were not

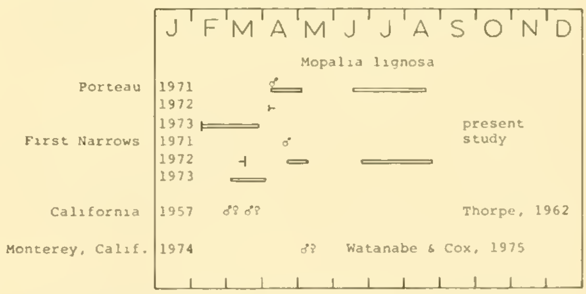

FIG. 9. Mopalia lignosa. *Summary of spawning observations.*

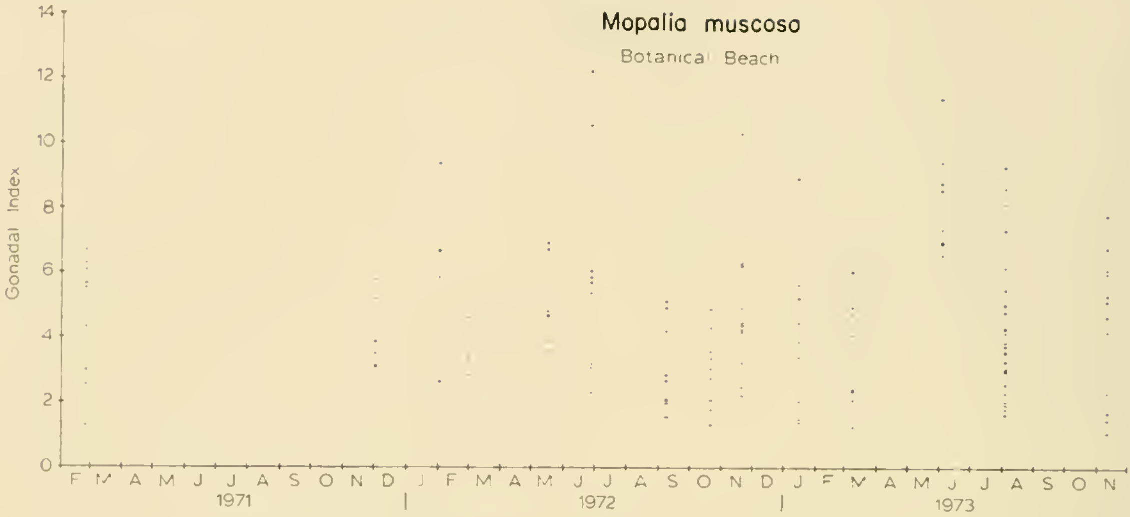

FIG. 10. Mopalia muscosa. *Gonadal index values for individuals collected at Botanical Beach.*

separated, mean gonadal indices were not calculated. Figure 10 shows the gonadal index value of each animal collected on 15 dates at Botanical Beach during 1971 through 1973. At all times in the year, mature and spent animals were found and no peak period of reproductive activity was evident. However, animals within any one pool tended to have similar gonadal indices. For example, on 4 August 1973, five animals from a pool at 2.6 m above LWST had indices ranging from 1.9-4.2, whereas five animals from a pool at 1.8 m had values of 5.0-8.6. To determine seasonal trends in *Mopalia muscosa*, it would probably be necessary to make collections throughout the year from a specific pool which contained enough animals to sustain this amount of sampling.

There are reports of observed spawnings or of gonadal index decreases in *M. muscosa* in all seasons of the year (Fig. 11). Barnawell (1954) found a high proportion of individuals with large gonads throughout the year in San Francisco

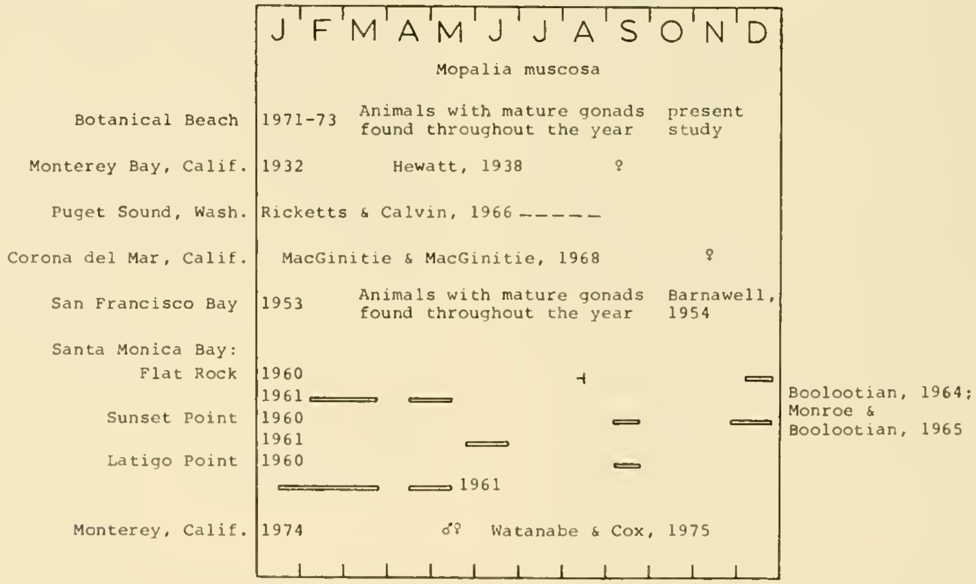

FIG. 11. Mopalia muscosa. *Summary of Spawning observations.*

Bay. In Santa Monica Bay, California, Boolootian (1964) and Boolootian and Monroe (1965) indicated that in three different locations there were major drops in the mean gonadal index during the winter and spring, but their data also indicate that animals with mature gametes were present even when the mean gonadal index was low.

In conclusion, in contrast to the other species, in *Mopalia muscosa* reproductive events are not closely coordinated amongst animals in single geographical locations. In any season, some animals may be undergoing gonadal growth and others may be spawning.

Control of Gonadal Growth

There are several patterns in the timing of gonadal growth in the genus *Mopalia*. In *Mopalia ciliata* gonadal growth starts in the early summer and continues until a peak is reached in mid-winter. In contrast, in *Mopalia laevior* the gonads remain small during the summer and there is rapid gonadal development during the autumn and early winter. Surprisingly, both patterns occur in *Mopalia hindsii*: gonadal growth starts in the summer in the subtidal population at First Narrows, and in the autumn in the intertidal populations at Botanical Beach and Monterey Bay. These two patterns of gonadal development are widespread in shallow water marine invertebrates of temperate and polar seas. For example, in concurrent studies in the same study areas, gonadal growth started in the summer in the chitons, *Tonicella lineata* and *Tonicella insignis*, and in the urchin, *Strongylocentrotus drocbachiensis* (Himmelman, 1976). In the latter reference, I have already discussed the possible environmental factors which might be controlling these patterns. Briefly, the initiation of gonadal growth in the summer may be influenced by high temperatures or steadily decreasing photoperiod. Possibly appropriate light sensitivities were shown by laboratory studies, in which I found significant changes in the rate of movement of the Mopalias in response to small changes in light intensity (Himmelman, unpublished). The initiation of gonadal growth in the autumn may be stimulated by lowered or steadily declining temperatures. The latter changes could also be important in the coordination of intermediate gametogenic events, such as vitellogenesis, in the species which begin gametogenesis in the summer. The final maturation phase of gametogenesis could be stimulated by minimal annual temperatures, the change to increasing temperatures, or the rapid change from decreasing to increasing photoperiod. These considerations are, of course, speculative and the actual factors will not be elucidated until experiments, in which one factor is varied at a time, are performed.

The data on gonadal growth in *Mopalia lignosa* is less clear. There appears to be gonadal growth following spawning periods in late-winter to early-spring, as well as in the autumn after summer spawning activity. There is no obvious widespread environmental factor that is correlated with both these periods of gonadal growth. Possible gonadal growth is stimulated by some local factor, such as food availability.

Control of Spawning

Spawning times vary in different *Mopalia* species and only *M. ciliata* and *M. laevior*, which spawn together in the spring, show the same pattern. Temperature is most frequently considered to govern spawning in marine invertebrates. At First Narrows in the present study, the late April spawning of *M. laevior* in 1972 and the early April spawning in 1973 can be related to temperature, since both spawnings occurred when temperatures reached 7.6°C. However, temperatures at First Narrows were similar in the spring of 1973 and 1974, and thus temperature differences would not account for the abrupt spawning of *M. laevior* and *M. ciliata* in 1973 compared to the poorly defined spawnings in 1974 (Fig. 4, 6). In 1974, sea temperatures when *M. ciliata* spawned were warmer at Botanical Beach (about 9°C) than at First Narrows. The Botanical Beach population was in the intertidal zone, and therefore subjected to more varying temperatures than the subtidal population at First Narrows. At Porteau, a thermograph at the collection site showed only a slow increase from 7.5 to 8.3°C during the two week period when *M. laevior* spawned. Thus, it is apparent that the relationship between temperature and spawning

in *M. ciliata* and *M. laevior* varies in different places and years.

In concurrent studies on other invertebrates, including the chitons, *Tonicella lineata* and *Tonicella insignis*, and the urchin, *Strongylocentrotus droebachiensis*, I found similar inconsistencies between temperature and spawning in the field (Himmelman, 1976). Also, attempts to induce the above animals to spawn in the laboratory (using animals collected just prior to spawning in the field) by exposing them to temperatures warmer or colder than in the field, as well as to sudden changes in temperature, were not successful (Himmelman, 1975).

On the other hand, spawning in *M. laevior, M. ciliata, T. lineata, T. insignis* and *S. droebachiensis* is closely correlated with the spring phytoplankton bloom (Himmelman, 1975, 1976). For example, the abrupt spawning of these species at First Narrows and Porteau in 1973 coincided with a sudden outburst of diatoms. In 1974, the spring bloom was delayed and less well defined, and this corresponded to the prolonged and less well defined spawnings in that year. Laboratory studies on *T. lienata, T. insignis* and *S. droebachiensis* demonstrated that spawning could, indeed, be induced by exposing ripe animals to natural phytoplankton at approximately bloom concentrations (Himmelman, 1975). There is no experimental evidence that phytoplankton causes spawning in *M. ciliata* and *M. laevior* but the coincidence is persuasive.

The cues for spawning in *Mopalia lignosa* and *Mopalia hindsii* are less clear. At Porteau in 1971, *M. lignosa* appeared to spawn once in late April and a second time in the summer, thus under considerably different environmental conditions. Also at First Narrows, the three *M. lignosa* collected on 18 March 1972 were in spent condition, suggesting that there has been spawning while temperatures were near the annual minimum and prior to the spring phytoplankton bloom. The data for 1973 are scant. One animal collected at Porteau on 27 March, and two from First Narrows on 30 March had depleted gonads, suggesting that spawning in 1973 preceded the bloom. Thus, neither temperature nor phytoplankton appears to be important in the spawning of *Mopalia lignosa*, and the actual spawning stimulus remains elusive.

In the present study, *Mopalia hindsii* had a single annual spawning, but the timing of this event preceded the spawning of *M. ciliata, M. laevior*, and other species which spawn in synchrony in the spring. At First Narrows, *M. hindsii* spawned in 1973 and 1974 during the period when temperatures were near the annual minimum, or just starting to increase. At Botanical Beach, *M. hindsii* was in spent condition before spawning was completed in *M. ciliata, T. lineata* and the black leather chiton, *Katharina tunicata* (Himmelman, 1976). Collections at this location were not made frequently enough to show whether the spawnings of *M. hindsii* preceded those of *S. droebachiensis*. Observations from earlier studies in Monterey Bay (Fig. 3) can be compared to environmental data for the same area (Bolin and Abbott, 1963). As in my study, there was a late winter spawning in 1956 and 1957 coinciding with near minimal sea temperatures. Surprisingly, the mean gonadal index showed a slow decline from November 1957 through spring 1958. This unusual pattern may be related to the unusually warm temperatures in 1958. This was the warmest year in Monterey Bay in a 40 year period and temperatures during the winter of 1957-1958 were near normal summer levels. The spawning periods of *M. hindsii* in Monterey Bay were not associated with periods of heavy phytoplankton abundance. In summary, spawning in *Mopalia hindsii* is usually associated with near minimum temperatures during late winter, and is completed before the spring phytoplankton outburst.

In *Mopalia muscosa* reproductive events are less coordinated, amongst animals in single locations, than in other species in the present study. At Botanical Beach, seasonal trends in reproductive activity were not evident in the data from animals collected from pools in various parts of the mid-intertidal region. In an earlier study in Santa Monica Bay, California, the mean gonadal index followed an irregular pattern, although some trends were suggested (Boolootian, 1964). The marked irregularity of reproductive events in *M. muscosa* is probably related to its unique vertical distribution. Unlike the other species, it is restricted to the intertidal region, and at Botanical Beach it was most abundant in pools at 1.8-3.0 m above LWST. The fact that animals

from specific pools were in similar condition, but not animals from different pools, suggest that reproduction in this species is controlled by environmental conditions in the immediate vicinity of the animals, therefore, by such factors as pool size, intertidal height, and food conditions. Widespread environmental conditions, such as temperature, photoperiod, and phytoplankton abundance, appear to be less important in controlling reproduction in *M. muscosa.*

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Early discussions on the indentification and ecology of the Mopalias with Dr. Ian McTaggart Cowan stimulated my interest in these animals. I am grateful to Drs. Helga Guderley, Thomas Carefoot and McTaggart Cowan for valuable comments on the manuscript. Helga also contributed with her unique ability at finding Mopalias at Botanical Beach. Dr. Norman Wilimovsky was generous in making the facilities at Botanical Beach available to me. During this study, I was a recepient of a National Research Council of Canada scholarship, and was aided by a NRC grant to T. Carefoot.

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GONIOBASIS VIRGINICA (GASTROPODA: PLEUROCERIDAE) IN THE CONNECTICUT RIVER

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ABSTRACT

The Connecticut River in New England is the northeastern range limit of the pleurocerid snail Goniobasis virginica *(Gmelin) where smooth shells predominate over spirally lirate shells, while color-banding is present only on younger specimens. Individuals occur only in areas where shallow rocky reefs are developed. Oviposition probably commences in spring and continues through to at least July. Range contraction over the last 80 years is believed to be the result of pollution, especially downstream where high water temperature and pH create adverse conditions.*

The Virginia river snail, *Goniobasis virginica* (Gmelin, 1791), although well-known to 19th century naturalists as an inhabitant of large Atlantic coast rivers, was not reported from the Connecticut River until the 20th century (Pilsbry, 1892; Winkley, 1901). Subsequent to these papers, a number of small collections were made of this species in the Connecticut River which eventually were transferred to the Museum of Comparative Zoology, Harvard University. Thereafter, the lower Connecticut River was considered to be the northeastern terminus of the total range of *G. virginica* (Goodrich, 1942).

Like most major rivers in the United States, the Connecticut River has been subjected to various forms of pollution as well as dam construction. Each has resulted in the general degradation of the quality of the river's water. The removal of a magnificent salmon, shad and sturgeon fishery, chiefly through the erection of dams, was well-documented by the 19th century (Netboy, 1968). However, little information has appeared regarding the fate of lesser esteemed organisms in the Connecticut River, particularly the benthic invertebrates.

The fortunate existence of early voucher collections of *G. virginica* from the Connecticut River in the Museum of Comparative Zoology has permitted an assessment of the present status of the snail in the Connecticut River. The present paper attempts to provide some data on the present distribution and population structure of *G. virginica* in the Connecticut River as well as information regarding the snail's biology.

METHODS AND MATERIALS

To establish a permanent record of the continued presence of *G. virginica* in the Connecticut River collections were made from August, 1978, to June, 1979, in areas known to be inhabited by this snail. Specimens were narcotized in mentholated water, fixed in a 10% formalin solution and stored in 70% alcohol. The collections (UMA Nos. MO. 1065, 1105, 1107) have been deposited in the Museum of Zoology, University of Massachusetts at Amherst. Conchological material from the same areas has been deposited in the Museum of Comparative Zoology, Harvard University and the American Museum of Natural History, New York. Existing collections of *G. virginica* from the Connecticut River were analyzed for historical distributional information and for range determinations. Measurements taken on all specimens included only aperture height as shell height and width were affected by erosion. However, five of the largest specimens were measured for total length to determine maximum shell size.

Live material was retained in a ten gallon aquarium to monitor activity. Specimens were successfully maintained for five weeks after which they were released. Supplementing field collections, water analyses at two stations, Suffield and Warehouse Point, Connecticut, were performed on June 18, 1979, when the river level

was low. Free carbon dioxide (CO_2), DO and pH were determined in the field using a Hach CA-10 portable water chemistry kit. Additionally, water samples were brought to laboratory facilities at the University of Massachusetts. Total hardness was ascertained by use of a Hach HA-4P hardness kit while pH was checked for accuracy by a calibrated Fisher Accumet pH meter. Individual chemical analyses, including diagnosis of the presence of heavy metals, were performed by the Environmental Quality Engineering Facility, Water Analysis Laboratory, University of Massachusetts. Also, to estimate population density, meter square (M^2) grids were established at Suffield and Warehouse Point, Connecticut, on June 18, 1979. Three grids ranging from .005 to .650 meter in depth were sampled at Warehouse Point while two grids ranging from .000 to .350 meter in depth were sampled at Suffield.

Finally, 14 specimens, collected on 24 June, 1979, were preserved in 10% formalin and serially sectioned for determination of gonadal activity. Individual gonads were sectioned at eight microns, dehydrated in an alcohol series and stained with Delafield's hematoxylin and eosin or fast green. Five slides were prepared for each specimen.

RESULTS AND DISCUSSION

Biology

Goniobasis virginica often expresses two shell morphologies, a smooth form and a lirate form, the latter historically given the nomen "*multilineata*" (Tryon, 1873). Pilsbry (1892) observed both forms in the Connecticut River. Presently a lirate phenotype is found among Connecticut River shells of *G. virginica*, however, the characteristically raised lines are best developed only younger specimens with an aperture height of about seven millimeters. Larger specimens usually have recognizably raised spiral lines confined to the lower third of the body whorl. Among a large sample of dead shells, lirate forms comprised 17 percent of the total sample (122 specimens). Pilsbry (1892) further noted that Connecticut River specimens of this species were large. Harman and Berg (1971) gave maximum lengths of 27.5 to 31.0 mm (aperture height, 9.0 to 11.0 mm) for material they collected in New York. Recent Connecticut River animals are comparatively larger, ranging from 30.8 to 32.5 mm total length (five largest specimens, $\bar{X}$ = 31.3 mm) and have aperture heights of 11.4 to 12.2 mm.

External color markings are subdued on recent Connecticut River snails. Younger specimens (to seven millimeters aperture height) often display a single chestnut color band on only the body whorl. Larger adults show no banding. Museum specimens collected around 1900 from the Connecticut River often show two similarly colored parallel bands on the lower portion of the shell of younger specimens.

Recognition of size classes and identification of cohort structure was not possible due to complete overlap of variously aged specimens. Dazo (1965), summarizing the available data on egg laying cycles in *Goniobasis* spp., showed that the season generally begins in early spring and lasts through the summer. The only reference specifically dealing with *G. virginica* (Winsor, 1933) cites egg laying as occurring in June in Maryland. Connecticut River *G. virginica* probably lays eggs from spring to July. Histological inspection of the gonads of 14 specimens showed that by June, males were spent and females only occasionally contained eggs in the ovary. Captive females held in an aquarium continued to lay small clutches of one to four eggs through July.

Harman (1972) has characterized *G. virginica* as a slow current, "clean cobble" inhabiting species. The present study supports Harman's diagnosis as this snail predominantly favors firm, clean substrates in the Connecticut River. The remaining micro-populations of *G. virginica* in the Connecticut River are found only in areas where the current continuously washes lithic surfaces. Animals are totally absent from intervening silt covered embayments and beaches. The three localities surveyed supporting aggregations of *G. virginica* were unique in that the accretion of rocks and gravel, brought about by both natural and artificial factors, has resulted in a "funneling" effect, thus concentrating river flow over reduced area. One site is a rocky delta that was built up at the mouth of a stream.

The other two sites exist underneath highway bridges, where residual land fill combined with accumulated rock debris has created a shoal between the shoreline and the nearest bridge support. Reefing in the above localities intensifies the river's current and, hence, increases abrasion

FIG. 1. *An adult specimen of* Goniobasis virginica *from the Connecticut River (× 1.5). Note algal growth on shell.*

of the rock surfaces thereby providing a clean substrate for habituation by snails.

Individuals of *G. virginica* in the Connecticut River host a number of epizootics and parasites. Dense growths of algae (Fig. 1) adorn the shells of older specimens. Occasionally thick colonies of the Entoproct (Bryozoan) *Urnatella gracilis* Leidy also cover the shell of some specimens. Internally, rediae and sporocysts of an undetermined species of trematode are sometimes found in high numbers in reproductive tissues (Fig. 2).

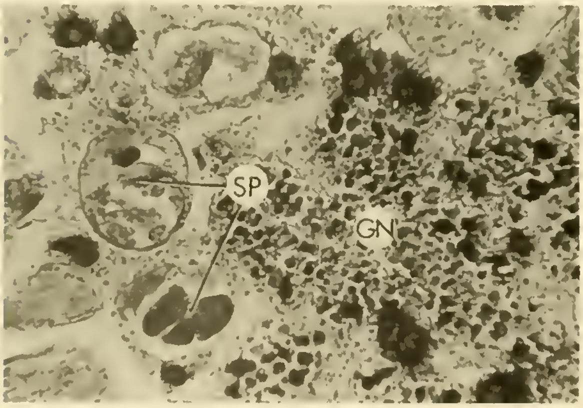

FIG. 2. *Photomicrograph of a section through the viscera of a specimen of* G. virginica *(× 100). GN-Gonadal tissue, SP-sporocysts of parasitic trematode.*

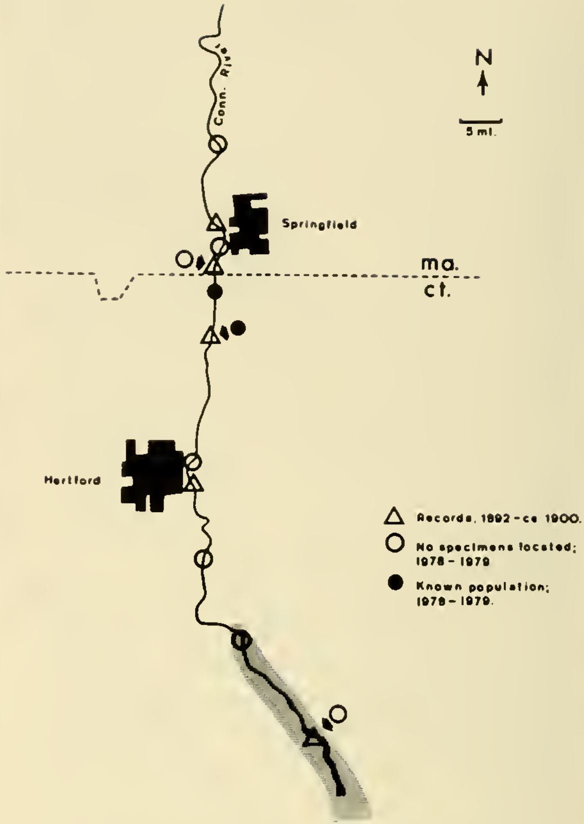

FIG. 3. *Map of the Connecticut River in southern New England showing former and present distribution of* G. virginica. *Shaded area indicates portion of river affected by the salt wedge.*

Distribution

Based on collections existing in the Museum of Comparative Zoology at Harvard University, supplemented by a few specific references (Pilsbry, 1892; Winkley, 1901), *G. virginica*, at the turn of the century, occupied a 60-mile range within the Connecticut River. Recent search, however, has revealed that *G. virginica* presently survives in only a five mile stretch of the river between the Enfield-Suffield area and Warehouse Point, Connecticut (Fig. 3). Massengill (1976) did not report it from Haddam, Connecticut, well within the species historical range.

Since the early collections were made after the larger dams were built, it is likely that the range contraction experienced by *G. virginica* resulted from deterioration of water quality, although the form of pollution responsible is unknown. Harman and Berg (1971) listed comparatively narrow

ranges of typical chemical characteristics in which *G. virginica* was found in New York, suggesting that *G. virginica* is intolerant of "dirty" conditions. Water analyses were performed at two sites on the Connecticut River on a day when stressful conditions would be most apparent due to very low water level and high atmospheric temperature (25C). The first site at Suffield, Connecticut, suggested conditions comparable to those in which *G. virginica* is found in New York (Harman and Berg, 1971) (Table 1). However, the second site, Warehouse Point, revealed high pH and water temperature (Table 1). Other parameters were within expected limits although dissolved oxygen was high. Warehouse Point is the farthest downstream *G. virginica* occurs in the Connecticut River and is where the species shows the greatest biological difficulty. Qualitative sampling during May at Warehouse Point when water conditions were more ameliorable turned up only seven living specimens. Quantitative sampling later in June, using M^2 grids, produced no living animals, an indication of worsening conditions. The suffield cite contained 291 and 433 individuals per M^2 at two grids respectively. Graphic analysis of survivorship of adult animals utilizing aperture heights, was performed for two micro-populations, Suffield and Warehouse Point (Fig. 4). The contrast between curves A and C is produced in part by differences in sample size and shell size. Whereas curve A was derived from an adequately large sample (62 specimens) Curve C was generated by the only seven living specimens collected. Curve B, representing museum specimens collected around

TABLE 1. *Chemical characteristics of environments supporting populations of* G. virginica. *All concentrations in parts per million (ppm).* DO = *dissolved oxygen,* $CaCO_3$ = *hardness as calcium carbonate,* CO_2 = *free carbon dioxide.*

	Date	Air Temp.	Water Temp.	DO	$CaCO_3$	pH	CO_2
Suffield, Ct.	18 June 1979	25.0C	24.0C	11	42	7.6	10
Warehouse Point, Ct.	18 June 1979	25.0C	27.5C	14	44	9.0	0
New York (Harman and Berg, 1971)	1966 - 1967	- - -	- - -	7- 12.5	80- 160	7.8- 8.3	0- 4

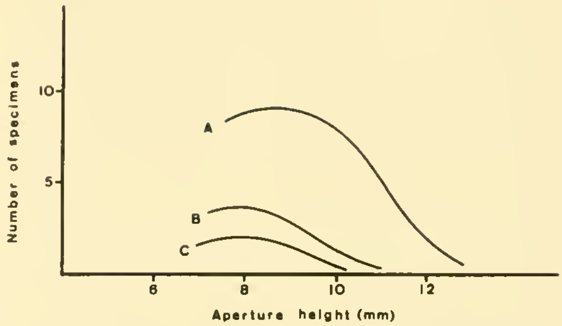

FIG. 4. *Distribution of shell sizes, based on aperture heights, of specimens in three collections of* G. virginica *from the Connecticut River: (A) Suffield, Ct., recent; (B) Springfield, Ma. to Hartford, Ct., about 1900; (C) Warehouse Point, Ct., recent. Curves were fitted to a scatter plots which can be furnished upon request.*

1900 between Hartford, Connecticut and Springfield, Massachusetts, is also representative of a small sample (10 specimens) and is included only for comparative purposes. Despite the conditions alluded to above, it is evident that Suffield snails are as large as, or larger than, snails found at the beginning of the present century in similar localities. Warehouse Point snails, however, do not achieve the same sizes of the other samples suggesting that, at Warehouse Point, either growth is curtailed or death preceeds maximum development.

Additional chemical analyses were performed on Warehouse Point and Suffield water samples in hopes to pinpoint the cause of mortality among *G. virginica* at Warehouse Point. Although heavy metal content was low, both sites showed high ammonia (NH_3) levels (.10 ppm, Suffield; .14 ppm, Warehouse Point). Alone these values do not answer why differential survival rates exist at each site, however, the high water temperature and alkalinity at Warehouse Point, the source of which is unknown, may enhance ammonia toxicity (Hynes, 1960; Harman, 1974). During warmer months, toxic ammonia probably eliminates those specimens that gain a foot hold at Warehouse Point during cooler periods.

The future holds an uncertain prognosis for the continued existence of *G. virginica* in the Connecticut River. Dispersal by snails, either up or downstream is controlled by the snail's ability to find suitable substrate to establish self-sustaining

populations as found at Suffield and Enfield. Furthermore, downstream movement, which would seem the direction of least resistance, is blocked by adverse water conditions as demonstrated at Warehouse Point. Although the surviving pockets of snails at Enfield and Suffield appear healthy, inability to disperse combined with short term fluctuations of water levels, caused by human activity, which periodically strand large numbers of snails out of water, place excessive pressure on a few reduced gene pools to maintain sufficient viability and adaptability to ensure the species survival in the Connecticut River.

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MICROSTRUCTURE OF THE CRYSTALLINE STYLE OF *SPISULA SOLIDISSIMA* (BIVALVIA: MACTRIDAE)[1]

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ABSTRACT

A method of fixation is introduced which allows light and scanning electron microscopy to be used in the study of the molluscan digestive style using the bivalve, Spisula solidissima *Dillwyn. Energy dispersive x-ray analysis of this style supports the hypothesis of internal liquification of older style material.*

The crystalline style is a relatively large mucoid rod present in several prosobranch gastropods and in all bivalves save the protobranchs (Purchon, 1968). This structure occupies the style sac which is completely separate in some species and continuous for all or part of its length with the midgut in others. The anterior end of the style projects into the stomach cavity and the entire structure is believed to be rotated by the cilia of the epithelium lining the style sac. Rub-

[1]University of Delaware College of Marine Studies Contribution No. 78101

bing of the stomach epithelium by the style tip is avoided by the presence of a protective gastric shield.

The style is approximately 80% water and is composed mainly of mucoproteins (Bailey and Warboys, 1960; Doyle, 1966). Bailey and Warboys (1960) found that although 67% of the dry weight of the style of *Pinna mobilis* was protein, much of this protein was associated with carbohydrates; there were only negligible amounts of enzymatic proteins. The most common sugars making up the carbohydrate fraction are hexosamine, galactose, and fucose (Hashimoto and Sato, 1955; Bailey and Warboys, 1960; Doyle, 1966).

Mechanical functions attributed to the style include the stirring of stomach contents, trituration of particles against the gastric shield, retrieval of food from the midgut and coating of abrasive particles with mucous (Bernard,, 1973). Physiological functions include use as a source of digestive enzymes and as a buffering agent (Bernard, 1973).

The enzymes reported present in style material are primarily carbohydrases (Kristensen, 1972; Wojtowicz, 1972). Most commonly present are amylase (Bailey and Warboys, 1960; Mathers, 1973; Langton and Gabbott, 1974) and laminarase (Sova *et al.*, 1970; Wojtowicz, 1972). Shallenberger *et al.* (1974) found laminarase to be the major style enzyme in *Spisula solidissma*. Other enzymes reported from bivalve styles are lipase (Mathers, 1973), maltase, and cellulase (Kristensen, 1972).

Study of the structure and mechanical function of the crystalline style has been hampered by its transitory nature. Morton (1970) and later Langton and Gabbott (1974) reported that many bivalves dissolve their styles during low tide and reform them at high tide. Kristensen (1972) demonstrated that formation of style material occurred only when animals were actively feeding. Yonge (1923) noted that the styles of bivalves possessing a separate style sac and midgut were always present and fairly persistant. Those bivalves whose style sac and midgut communicate were often found to lack a style or to possess one which dissolves rapidly upon removal from the style sac.

Because of the high water content of the style and its transitory nature few techniques for rigorous examination of its structure have been demonstrated. Some work using transmission electron microscopy has been accomplished through standard plastic embedding techniques (Wourms, 1970; Ghiselin, de Man, and Wourms, 1975).

This paper describes for the first time a method of fixation of crystalline styles which allows its examination by light or scanning electron microscopy. Due to the large size and high stability after dissection, the style of the clam, *Spisula solidissima* Dillwyn, (family: Mactridae) was used to demonstrate this method. This species has a gastropemptan stomach (type V according to the classification of Purchon (1960)) with a completely separated sac and midgut.

METHODS

Styles were collected from specimens of *Spisula solidissima* maintained in a running seawater table. Valves were cracked open and a lateral incision made into the stomach cavity. Styles were fixed in 10% Sorenson's phosphate buffered formalin with a small amount of acetic acid (0.06 ml acetic acid per 10 ml formalin) for approximately 24 hours. Dehydration was carried out by 8-12 hour changes in 30%, 50%, 70%, 85%, and 95% ethanol at 0°C. The material was then slowly warmed to room temperature and transferred to absolute ethanol. Transfer from 70% to 85% resulted in approximately twenty percent shrinkage. After dehydration, styles were critical-point dried (a Denton DCP-1) and mounted on stubs. Specimens to be viewed with the scanning electron microscope were coated with carbon and gold and viewed with a Cambridge Stereoscan Mark II and a Phillips SEM-501. Portions of styles used for elemental analysis were coated with carbon and examined qualitatively by energy dispersive x-ray analysis.

RESULTS

The style of *Spisula solidissima* possesses an extended anterior tip and is drawn out to an elongate point posteriorly (Fig. 1). The major length of the style is composed of numerous concentric longitudinally oriented lamellae. When viewed with light microscopy these lamellae surround an inner core of granular material. In a

FIG. 1. *Drawing of the crystalline style of* Spisula solidissima. *Scale bar equals 1 cm. A - anterior tip of the style, B - food bolus, C - head of the style, D - constricted zone, E - lamellae of the style, F - central core of granular material.*

scanning electron microscopy this granular material seemed to be very similar to the lamellar material (Fig. 2). Elemental analysis of these two zones by energy dispersive x-ray analysis also indicated that these two zones are identical in composition with reference to the two major elements detected, calcium and sulphur.

The constricted area posterior to the bulbous head of the style lacks a core of granular material. Under the light microscope this constricted zone possesses several rings on the exterior surface. These are similar to the impressions noted by Kristensen (1972) in styles of *Macoma balthica* (Linné). Scanning electron microscopy revealed that these rings actually consist of terraced layers of exterior lamellae (Fig. 3 and 4).

The bulbous head of the style is composed mainly of granular material with only a few lamellae present at the exterior surface. The narrow anterior tip extends from the head of the style and is pressed against the gastric shield at the left anterior wall of the stomach. This portion of the style is also composed of terraced lamellae similar to those of the constricted area (Fig. 5). Much of this tip is surrounded by a food bolus of amorphous material interspersed with occasional diatoms (Fig. 6).

DISCUSSION

The style had been thought to be secreted in the posterior end of the style sac replacing material lost to dissolution in the stomach. Using *in vivo* staining on styles of *Macoma balthica* and *Abra nitida* of European seas Kristensen (1972) found that new style material is added along the entire length of the style sac. This discovery was later substantiated by Bernard (1973) by labeling the style with barium. On the basis of his staining experiments Kristensen hypothesized that older style material moves inward to the central axis of the style, undergoes liquification and collapse, and is then forced anteriorly toward the stomach.

Examination of the structure of the style of *Spisula solidissima* tends to support the hypothesis of internal collapse and liquification of old style material described by Kristensen (1972). Both the lamellar and granular style material were similar in composition in respect to the two elements detected with energy dispersive x-ray analysis. Material from both regions of the style was also quite similar in appearance, although the granular material seemed more loosely organized. The similarity of these two regions also tends to refute independent secretion of lamellar and granular material hypothesized by Alexander and Rae (1974).

The present study suggests that formation of the style occurs entirely within the style sac. Rings described by Kristensen (1973, Fig. 1) on the collar of the style of *Macoma balthica* are similar in appearance to the terraced lamellae found on the style of *Spisula solidissima* (Fig. 3 and 4). The edge of each ring represents the effective anterior limit of the style sac during secretion of each lamella. This suggests that the style decreases in diameter and is shifted incrementally in an anterior direction prior to the laying down of new lamellae in the style sac.

The lack of food material on the exterior surface of the style of *Spisula solidissima* fails to support Bernard's (1973) hypothesis that the style sac epithelium is a digestive surface. Histochemical studies by Mathers (1973) of *Ostrea edulis* and *Crassostrea angulata* have demonstrated that the style sac epithelium does not show reactions typical of an area of absorption while the stomach and midgut epithelium do. Evidently the major portion of the style sac

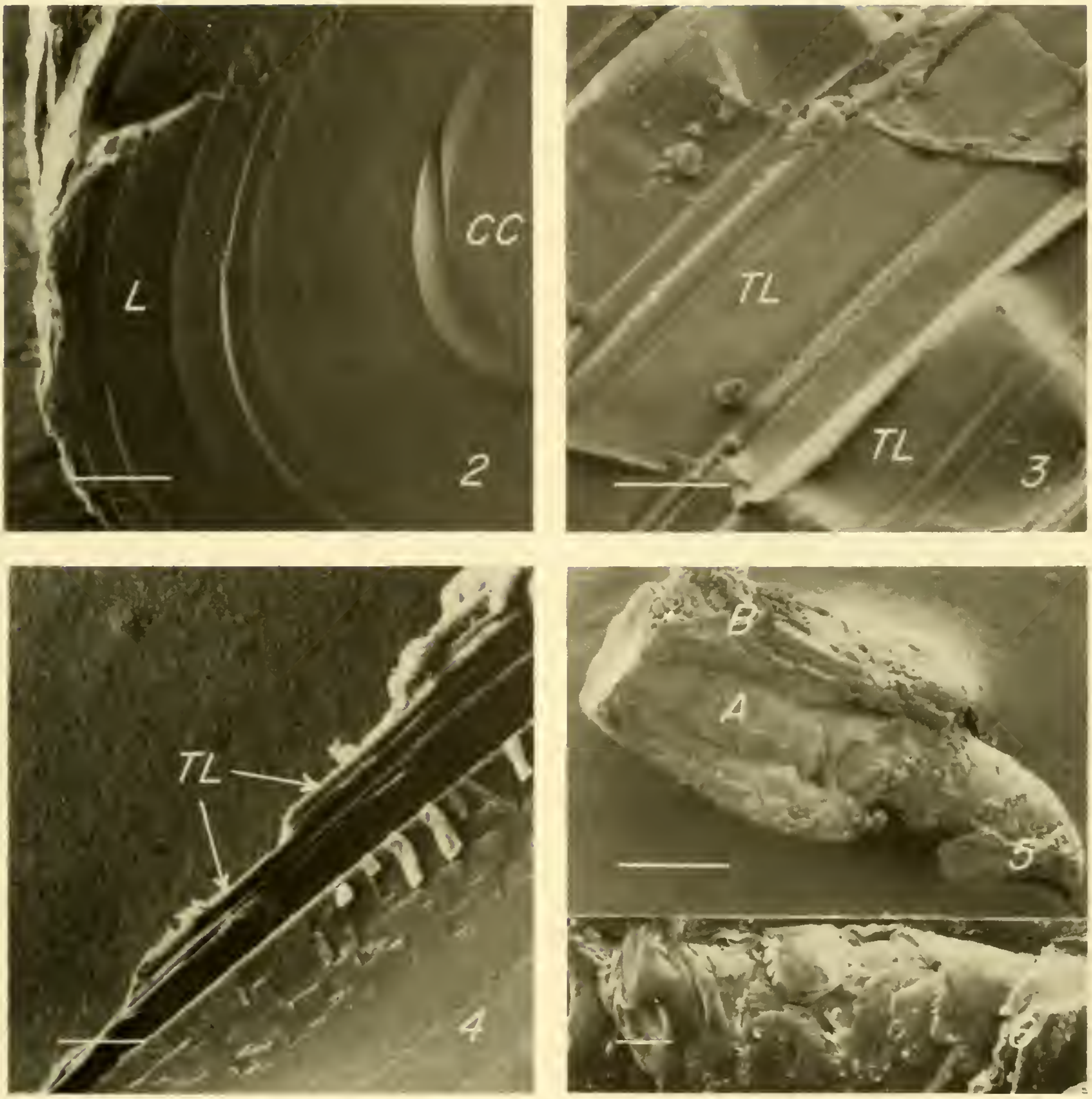

FIG. 2-6. *Scanning electron micrographs of the crystalline style of* Spisula solidissima. 2, *Cross section at the approximate midlength of the style. Scale bar equals 100 um. CC - central core of granular material, L - lamellae.* 3, *Exterior surface at the constricted area of the style. Scale bar equals 50 um. TL - terraced lamella.* 4, *Longitudinal section of the constricted area of the style. Scale bar equals 100 um. TL - terraced lamella.* 5, *Anterior tip of the style with the encircling food bolus partially removed. Scale bar equals 50 um. A - anterior tip of the style.* 6, *Terraced organization of the lamellae at the anterior tip. Scale bar equals 100 um.*

epithelium function mainly in ciliary rotation and forward movement of the crystalline style.

In addition to the style of *Spisula solidissima* that of the Mahogany Clam, *Arctica islandica* (Linné) was also fixed successfully in the present study using this same procedure. This success suggests that this method may be employed with a wide range of gastropod and bivalve species to compare styles from a broad range of stomach and feeding types. Changes in style morphology during tidal cycles and in response to varying environmental factors, subjects of considerable cur-

rent interest (Reid and Reid, 1969; Morton, 1970; Kristensen, 1972; Bernard, 1973; Langton and Gabbott, 1974), can also be explored with this method.

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A NEW PREPARATION FOR OBTAINING CHROMOSOME SMEARS IN *HYDROBIA* (HYDROBIIDAE)

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Hydrobia sp., probably *hemphilli* (Pilsbry, 1933), is found in numerous cold springs of eastern Washington. Comparative morphological, ecological, and cytogenetic studies have been initiated on selected populations of this snail to determine what biological variations occur within its eastern Washington range. This report is concerned with a new technique for obtaining chromosome spreads from *Hydrobia*.

Few techniques have been described for obtaining chromosome spreads in snails. Burch (1968) treated tissue-cultured ovatestes cells with a colchicine solution and demonstrated metaphase chromosome spreads in land snails. Babrakzai

and Miller (1974) used a similar colchicine squash technique on pulmonate land snails. Patterson (1971) treated freshwater embryos with an isotonic velban solution and demonstrated mitotic metaphase chromosome spreads. Stern (1974) used a similar velban technique on snails of the family Oleacinidae. The success of these techniques requires complex equipment and lengthy procedures. The method described in this paper requires little apparatus and is completed with minimal time and effort. The technique described has been applied only to *Hydrobia* sp. but may have application in other molluscan groups.

Large numbers of *Hydrobia* sp. were collected from five populations in eastern Washington. A small hole was made in the second body whorl of the shell using a small probe. This was to allow passage of a micropipette into the body mass of the snail. The snails were injected with 2.67 *ul* of 10^{-3} colchicine using a Prior England micropipette injection system and placed in finger bowls containing distilled water for two hours. The shell of the snail was gently crushed and the gonads removed, placed on a glass slide and stained in 1 percent iron-aceto-carmine for seven minutes. The tissue was completely covered with the stain. A coverslip was added and gently tapped with a metal forceps to effect spreading of the tissue. Excess stain was removed with a paper towel and the slide was placed between two sheets of paper toweling and slowly compressed by thumb pressure.

Figure 1 shows metaphase chromosomes of *Hydrobia* sp. (2n = 36). Chromosome spreads between the various populations were numerically identical. Spermatogenesis occurred in all populations during the summer months. One population, sampled through November, showed an apparent increase in spermatogonial activity. Egg production was initiated in October in this population. Representative shells of *Hydrobia* sp. are shown in Figure 2.

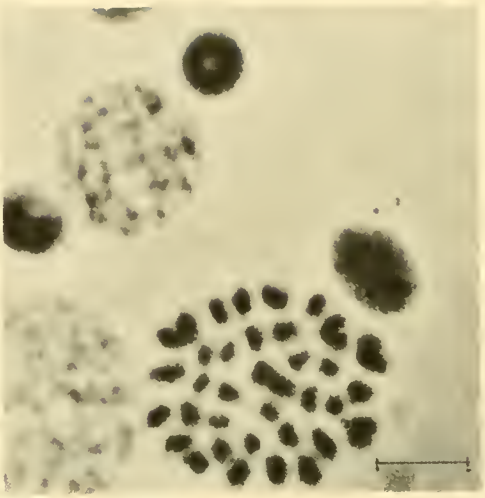

FIG. 1. *Metaphase chromosome spread of* Hydrobia *sp. Scale line = 25 micra.*

FIG. 2. *Shells of* Hydrobia *sp. Scale line = 1 mm.*

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SNAILS FROM QUATERNARY VALLEY FILL AT CHACO CANYON, NEW MEXICO

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ABSTRACT

Nine species of land and aquatic snails occur in prehistoric alluvium at Chaco Canyon, New Mexico. Shells of Stagnicola cockerelli *in the main valley fill indicate the presence of intermittent pools on the undissected canyon floor during Basketmaker and Puebloan occupation. Erosion of the post-Bonito channel eliminated the aquatic snails by destroying their habitats. The drift snail fauna reported by Drake (1948) may be reworked from the prehistoric alluvium.*

In northwestern New Mexico the Chaco River has cut an 80-meter deep canyon through thick-bedded sandstone. The canyon is called Chaco Canyon, probably a Spanish variant of Navajo words and an old name which was in use before American contact (McNitt, 1964). During the late Quaternary, Chaco Canyon was filled with thick deposits of mud, sand, and gravel of which over 6 meters are now exposed in the banks of the Chaco River arroyo. In the 1920's, during the National Geographical Society's excavation of Pueblo Bonito, one of the large number of abandoned pueblos for which Chaco Canyon was named a national monument, Kirk Bryan investigated the geology of the alluvial valley fill and reported the occurrence of snail shells, including an aquatic form now known to be *Stagnicola cockerelli* (Pilsbry) (see Bryan, 1954). Later, during archeological surveys and excavations at Chaco in 1946 and 1947 by the University of New Mexico, a major effort was made to document the modern molluscan fauna (Drake, 1948). Although no living snails were discovered, shells of fifteen species and subspecies of land and freshwater forms were found in drift, around ruins, on anthills, and around seeps and springs in the sandstone cliffs.

During 1972 and 1973 the valley fill at Chaco Canyon was again investigated, this time to refine and radiocarbon date the stratigraphy reported by Bryan and to analyze the pollen content of the alluvium (Hall, 1977). During inspection of the arroyo walls twelve localities were discovered that yielded a total of 289 fossil shells of land and freshwater snails. Shells were recovered from each of the alluvial units described from Chaco Canyon. The units are Fajada (late Pleistocene), Gallo (about 7,000 to 2,400 years ago), Chaco (2,200 to 850 years ago), Post-Bonito (600 years ago to 1860 A.D.), and Historic (1935 to present). Details of these stratigraphic units are presented elsewhere (Hall, 1977). The snail species are listed in Table 1 by alluvial unit and by numbers of individuals recovered.

Most of the shells found in the canyon fill are from the Chaco unit, probably because it is the principal fill unit in the canyon and more of it is exposed in arroyo walls. The most abundant shell, and the only form found in all five units, is a succineid, probably *Succinea*. Drake (1948) identified *S. grosvenorii* from Chaco Canyon, and the fossil succineid shells are probably the same form. Other abundant terrestrial species are *Pupoides hordaceus* (Fig. 1), *Vallonia cyclophorella*, and *Hawaiia minuscula*. Two freshwater snails were recovered from the canyon fill: *Stagnicola cockerelli* (Fig. 1) and *Gyraulus* sp. Drake (1948) reported *G. circumstriatus* from Chaco Canyon. However, the single fossil *Gyraulus* shell recovered from the Chaco unit is broken and cannot be identified to species. Overall, seven of the eleven land forms and two of the four freshwater forms reported by Drake were recovered as fossils from the alluvium.

Paleoecology

The deposition of the main valley fill (Chaco unit of Hall, 1977) coincides with the Basket-

TABLE 1. *Fossil and living gastropods from Chaco Canyon, New Mexico.*

Species[1]	*Fajada unit*	*Gallo unit*	*Chaco unit*	*Post-Bonito unit*	*Modern 1972-73*[2]	*Drift (Drake, 1948)*
Aquatic						
Fossaria parva (Lea)						X
Gyraulus circumstriatus (Tryon)						X
Gyraulus sp.			1			
Helisoma tenue cf. *sinuosum* (Bonnet)						X
Stagnicola cockerelli (Pilsbry)			21	1		X
Terrestrial						
Gastrocopta pellucida hordeacella (Pils.)			2			X
Hawaiia minuscula (Binney)		1	11			X
Hawaiia minuscula form *alachuana* Dall						X
Pupilla cf. *blandii* Morse						X
Pupilla hebes (Ancey)			1			X
Pupoides albilabris (C. B. Adams)				1		X
Pupoides hordaceus (Gabb)		2	27			X
Succinea grosvenorii Lea						X
Succinea sp.[2]	2	1	185	8	X	
Vallonia cyclophorella Sterki		5	20			X
Vallonia gracilicosta Reinhardt						X
Vertigo ovata (Say)						X

[1] The species listed by Drake (1948) are duplicated here without alteration except for *Stagnicola bulimoides cockerelli*.
[2]In general, identifications of the family Succineidae are reliable only through anatomical studies of the animal itself; shells alone are of little value for species determination (Taylor, 1960, p. 77; Patterson, 1971).

maker and Puebloan occupation of the area between about 600 and 1200 A.D. and, accordingly, the environmental reconstruction of the alluvium applies to the prehistoric human ecology of Chaco Canyon. The presence of aquatic snails and the

FIG. 1 *(left)* Stagnicola cockerelli *from Chaco unit alluvium, 7.2 mm in height; (right)* Pupoides hordaceus *from Chaco unit alluvium, 3.5 mm in height; shells not to same scale.*

impressions of rushes in the main valley fill were cited by Bryan (1954, p. 50-51) as evidence for more moist climate at Chaco Canyon. Bryan also pointed out that the aquatic shells were found in the post-Bonito channel fill as well (Post-Bonito unit of Hall, 1977) but concluded that the evidence for environmental conditions during the time of prehistoric occupation was sparse.

A pollen analytical study of the Chaco Canyon valley fill suggests that the pinyon (*Pinus edulis*) and ponderosa (*P. ponderosa*) pine forests in the region were less abundant during Basketmaker-Puebloan occupation of the canyon than today and that, accordingly, the climate was drier then than it is today (Hall, 1977). A question that arises is: how does a drier climate reconcile with the occurrence of the aquatic snail *Stagnicola cockerelli*? The explanation probably lies with the geomorphology of the canyon floor. During the prehistoric occupation of the canyon and the deposition of the Chaco unit, a deep arroyo channel such as exists today was not present. Sedimentary structures in the Chaco unit indicates that runoff from storms spread over the valley

floor, perhaps in a network of shallow channels no deeper than 20 to 30 cm. Due to the imperviousness of the clayey Chaco alluvium (Judd, 1964, p. 230-231) it is likely that water collected in intermittent pools after each heavy rainstorm and formed a suitable habitat for *S. cockerelli.* This species ranges throughout the region today (A. B. Leonard, 1959; Pilsbry and Ferriss, 1906; Bequaert and Miller, 1973) where it has been collected from ponds and ditches that are seasonally dry (A. E. Leonard, 1943; Henderson, 1924). With the trenching of the canyon floor by the post-Bonito channel, the intermittent pool habitats were eliminated. Subsequent filling of the old arroyo channel may have reestablished conditions favorable for *S. cockerelli.* The few fossils of *S. cockerelli* in the later alluvium (Post-Bonito unit) may reflect the presence of another series of intermittent pools or the shells may be reworked from the older Chaco unit. At present a 10-meter deep arroyo channel bisects the floor of Chaco Canyon, and two summers of field work (1972 and 1973) produced no evidence of *S. cockerelli* or any other species alive there today.

The Chaco Canyon snail record illustrates the paleoecologic principle that snails, although excellent indicators of microhabitats, may be misleading as guides to regional climatic conditions. The record at Chaco Canyon suggests that *Stagnicola cockerelli* and perhaps the other aquatic species could inhabit the canyon floor as long as intermittent pools were present. When the canyon was trenched by the post-Bonito channel, the pools and the snails were eliminated. The pollen sequence indicates the climate became wetter during the post-Bonito channel cutting. The destruction of the aquatic snail's microhabitat, however, resulted in the elimination of the aquatic species from the canyon regardless whether the climate became wetter or drier. The presence of *S. cockerelli* in the Chaco unit alluvium means only that water was available in intermittent pools and does not necessarily mean that the climate was more moist then than it is now.

Fossils Reworked in Drift

Nine of the twelve species reported by Drake (1948) occur as well-preserved fossils in canyon fill (Table 1). Neither Drake nor this writer observed living snails at Chaco Canyon. There is a strong possibility that at least some and perhaps all of the shells Drake collected from drift were fossil shells eroded from the prehistoric alluvium. The shells collected from anthills could also be fossil, each one removed by ants during nest excavation into deeply buried alluvium and transported to the surface mound along with small gravels. Although shells found around seeps and springs in the cliffs could also be fossil, they are more likely recent. Drake does not mention which specimens were collected from the springs and which came from drift.

Modern Fauna

The writer discovered three possible colonies of a succineid, probably *Succinea,* and apparently the same species that occurs as a fossil in the canyon fill. The shells, all dead and bleached by the sun, occur loose in surface duff at topographically depressed places that are periodically inundated by runoff. The sites are (1) in Gallo Wash canyon just north of the Campground (center sec. 22, T. 21 N., R. 10 W.), (2) in a small area of the abandoned canyon floor northwest of the U. S. National Park Service Visitor Center (NW ¼ sec. 20, T. 21 N., R. 10 W.), and (3) in a small mud flat covered by sunflowers south of South Gap about 2 miles beyond the monument boundary (center sec. 27, T. 21 N., R. 11 W.). Isolated succineid shells also occur commonly in the present-day dry floor of Chaco River arroyo.

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DRILLING PREDATION ON SOME MIOCENE MARINE MOLLUSKS

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ABSTRACT

Drilling rates and stereotypy of drill hole position were examined on two bivalves and a gastropod from a middle Miocene assemblage in Maryland. The bivalves, Anadara elevata *Conrad and* Astarte thisphila *Glenn, show a reduction in predation rate with an increase in size. The gastropod,* Turritella plebeia *Say, does not appear to attain a size refuge against drilling. These results correlate well with other reports of drilling predation throughout the fossil record.*

The record of drilling by predatory snails and other organisms is often clearly preserved in fossil material. Paleozoic mollusks and brachiopods occasionally have drill holes which have been attributed to molluscan predators (Fenton and Fenton, 1931; Bucher, 1938; Cameron 1967). It is now generally agreed, however, that these holes were caused by non-molluscan borers (Fischer, 1962, 1966; Carriker and Yochelson, 1968), and that mollusks did not develop the boring habit to an appreciable degree until mid- to late-Cretaceous times with the appearance of the naticid subfamily Polinicinae and the muricacean genus *Hillites* (Sohl, 1969).

By the early Tertiary, drilling by naticids and muricids (as well as by other organisms such as octopods) had become quite widespread. A number of authors have described the drilling they observed in various fossil assemblages. See, for example: Fischer (1962, 1966), Siler (1965), Taylor (1970), and Adegoke and Tevesz (1974) for Eocene assemblages; Hoffman *et al.* (1974), Kojumdjieva (1974), and Thomas (1976) for Miocene assemblages; Thomas (1976), and Robba and Ostinelli (1975) for the Pliocene; and Berg and Nishenko (1975) for the Pleistocene.

As far as we can determine, with the probable exception of Taylor's 1970 discussion of drilling in an assemblage from the Paris basin, the above authors examined materials from previously sorted collections, rather than starting with the fossil material *in situ* in the surrounding

substrate. This paper reports on drilling in prey species that were sorted from a single large block of substrate in an attempt to eliminate any bias arising from collecting techniques (such as the discarding of broken shells, for example). Also, as shown by Kojumdjieva's (1974) extensive data on a Bulgarian Miocene formation, drilling frequency can vary considerably in local populations of a prey species. Such variance can be obscured in museum collections. We feel that our data on three carefully sorted species accurately reflect the predation rates sustained by the local populations.

MATERIALS AND METHODS

In the autumn of 1976 a very large cliff fall occurred near St. Leonards, Calvert County, Maryland, U.S.A., in the famous middle Miocene outcroppings known as Calvert Cliffs. (See Clark *et al.* (1904) for a complete review of these deposits.) The authors were present the day of the cliff fall, and determined that it came from Zone 17 of the Choptank formation. This is an exceptionally fossiliferous zone, consisting of a yellowish sand substrate embedded with an abundant and diverse fauna.

Our analysis was carried out on an eighteen kg. section from this fall. The material was allowed to air dry for two months, and then individual shells were carefully removed. Most gastropods and many bivalves did not fossilize sufficiently well to be useful for the analysis. However, three species fossilized well, and we sorted out all the specimens. Two bivalves and one gastropod were used: *Anadara elevata* Conrad, *Astarte thisphila* Glenn, and *Turritella plebeia* Say. Each specimen was measured to the nearest millimeter with Vernier calipers. The species were then divided into size classes, and drilling frequency and position were examined. For the bivalves, we made the assumption also made by other workers, that the drilling frequency in a population is double that observed on disarticulated valves.

The borers involved in this study were of the family Naticidae. The Muricidae are known from other formations in these Miocene beds, but are extremely rare in the Choptank formation; we did not see any in our sample. The most abundant naticid was *Lunatia heros* (Say), a very common species in the Choptank. Also present, though less abundant, was *Neverita duplicata* (Say). Those drill holes that were well preserved were of the truncated parabaloid nature characteristic of naticids (Carriker and Yochelson, 1968).

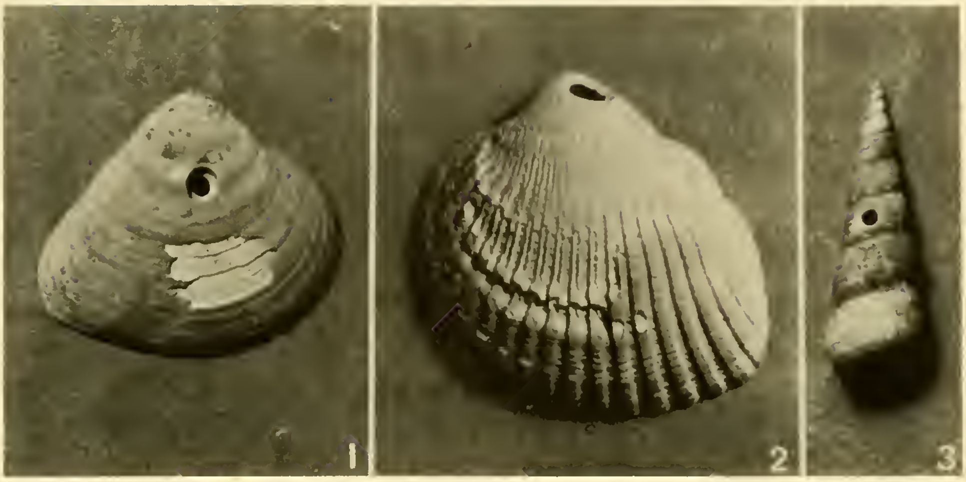
RESULTS AND DISCUSSION

Drilling frequencies for each of the three species are recorded in Table 1. It is immediately evident that *Anadara elevata* and *Astarte thisphila*, the two bivalves, exhibit a similar reduction in the rate of predation with an increase in size, whereas *Turritella plebeia* has a higher rate of predation at the larger sizes. The bivalves have relatively thick shells at their larger sizes, whereas *T. plebeia* is always a thin and delicate shell. This perhaps explains why this species does not appear to attain a size refuge, at least in this population.

The rates of predation observed for these three species are similar to those reported for another Miocene assemblage (lower Tortonian) from the Korytnica clays of Poland (Hoffman *et al.*, 1974). For *Anadara diluvii* (Lamarck) 7% of the 656 specimens were attacked, which is close to the 9% observed in the larger size class of *A. elevata* (Hoffman *et al.* do not give size classes). The three *Turritella* species listed, *T. badensis* Sacco, *T. bicarinata* Eichwald and *T. erronea* Cossmann had predation rates of 17%, 28%, and 25% respectively. Other authors cited in our introduction have found similar rates in Eocene material, although rates have also been recorded as high as 63% in *Mesalia*, a turritellid genus (Fischer, 1962).

A striking feature of the drilling in these shells is the degree of stereotypy of borehole position (Fig. 1). In *Anadara elevata* 100% of the suc-

Species	N	% Drilled
Anadara elevata		
10 - 25 mm.	35	31.4
25 mm.	54	9.3
Astarte thisphila		
10 - 20 mm.	9	22.2
20 - 30 mm.	81	10.0
Turritella plebeia		
10 - 20 mm.	18	16.7
20 - 30 mm.	63	28.5
30 - 40 mm.	20	35.0



FIGS. 1-3. *Characteristic Miocene naticid drill holes in* 1, Astarte thisphila, 2, Anadara elevata, *and* 3, Turritella plebeia.

cessful drill holes were central and high on the umbo. Interestingly, two of the three incomplete holes noted were on other parts of the valve. The holes in *Astarte thisphila* exhibited a broader scatter, but all were contained within the upper one third of the valve. In neither of these species was there any indication that one valve was drilled preferentially over the other. The drill holes were exactly evenly distributed between left and right valves in *Astarte thisphila*, and in *Anadara elevata* there was a very slight and not significant preference for the right valve.

Turritella plebeia also exhibited stereotypy in drill hole position. 98% of the holes were in the penultimate and third from last whorls, and 75% of all holes were on the apertural side of the shell.

Such stereotypy of drill hole position has been reported on all through the Tertiary and into the Recent. Fischer (1960) looked at 1,222 valves of *Pectunculus* (now *Glycymeris*) *pulvinatus* Lk. from the Lutetian of Grignon, and found most holes to be in the central region of the shell. Sohl (1969) found naticid borings preferentially located in the umbonal area of *Crassatellites undulata* Say, of the Miocene Yorktown formation; and Kojumdjieva (1974) reported a similar location for drill holes in *Anadara diluvii*. Thomas (1976), looking at *Glycymeris americana* (Defrance), reported a shift in preferred boring site from the middle to late Miocene. Stump (1975) found very localized borings in naticid gastropod prey of a Mexican Pleistocene assemblage, and Berg and Nishenko (1975) found stereotyped drilling by both Pleistocene and Recent naticids.

Thus stereotypy of drill hole position seems to be a common phenomenon, one that varies between species, and also at different times within the same species. Most authors seem to agree that this stereotypy reflects both prey size and shape, and the behavior of the predator. However, Boettger (1930) pointed out other factors to be considered. He found that the degree of stereotypy was affected by both naticid density and the depth of the substrate. Fewer predators and a deeper layer of substrate resulted in lessened stereotypy in his work, and these factors may play a role in other cases as well.

In conclusion, the data given here form the first report on drilling predation in mollusks from the Choptank formation of Maryland. They are in substantial agreement with much of the data from other locations and times, indicating that drilling rates and stereotypy of drill hole position have been remarkably consistent at least since the Eocene. Since local variations in drilling rates have been documented in the literature, we feel that it is most useful to analyze data from material collected from a single location in the table opposite.

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assistance, and their appreciation to Larry and Connie Smith for making possible the collection of the materials examined.

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MEETINGS

Symposia on feeding mechanisms of predatory mollusks and on the functional morphology of cephalopods, as well as field trips, an auction of shell literature, and a cruise on the Belle of Louisville will highlight the Annual Meeting of the **A. M. U.**, July 19-25, 1980, at Louisville, Kentucky. A cash prize will be offered for the best student paper. For further information write Dr. C. F. E. Roper, Division of Mollusks, National Museum of Natural History, Washington, DC 20560.

The **Western Society of Malacologists** will meet (with the AAAS) at the University of California at Davis, June 23-25, 1980. Pre-registration forms, due May 23, are obtainable from Dr. Vida C. Kenk, Dept. Biological Sciences, San Jose State University, San Jose, CA 95192.

The **Conchologists of America**, an organization mainly for amateur conchologists, will hold their annual meetings in Key West, Florida, August 6 through 9, 1980, with headquarters at the Casa Marina. This is three days after the Jacksonville Shell Show. For further information write Margaret Teskey, P.O. Box 273, Big Pine Key, FL 33043.

INVERTEBRATE FAUNULES OF LATE PLEISTOCENE AGE, WITH ZOOGEOGRAPHIC IMPLICATIONS, FROM TURTLE BAY, BAJA CALIFORNIA SUR, MEXICO

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ABSTRACT

Metazoan invertebrates representing 138 species, mostly mollusks, are enumerated and recorded quantitatively from six localities in marine terrace deposits of the Turtle Bay region on the Pacific Coast of Baja California Sur, Mexico. Faunules from two of the localities (B-3024 and (B-3025) contain warmwater (subtropical and tropical) elements and are referred to the late Pleistocene Magdalean Province of western Baja California on the basis of faunal comparisons with regional assemblages. The two Turtle Bay assemblages with warmwater indicators are probably correlative with an early phase of the Sangamon Interglacial Stage (isotopic Substage 5e). More precise dating of the faunules from these localities and reliable correlation of the four other faunules (localities B-3027, B-3007, 'B-33050, and B-3048), which apparently lack warm-water elements, must await absolute dating of the fossils.

This paper is dedicated to the memory of my esteemed colleague, Edwin C. Allison (1926-1971), who collected the fossils in 1956.

Edwin C. Allison (1926-1971)

Introduction

Turtle Bay [1] (Figure 1) is a small, protected embayment on the southwestern side of the Vizcaino Peninsula, Baja California Sur, Mexico (latitude 27° 41'N., longitude 114°52'W.; see Figure 1). In the summer of 1956, the late Edwin C. Allison, then of the Department of Geology, San Diego State University, amassed large numbers of Pleistocene marine invertebrates from several highly fossiliferous terrace deposits in the vicinity of Turtle Bay. Because of his primary interest in the older rocks of the area (cf. Allison, 1957; 1964), he asked me to join him in co-authoring a report on the terrace fossils of this paleontologically poorly known region of western Baja California Sur.

The identification of the megafossils was completed by me in 1960. Commitments to a heavy teaching schedule and to other research projects, however, prevented Dr. Allison from undertaking the writing of the sections pertaining to the

[1] Also known as Bahía Tortugas (the port of which is called San Bartolome or Puerto San Bartolomé), and henceforth cited as Turtle Bay.

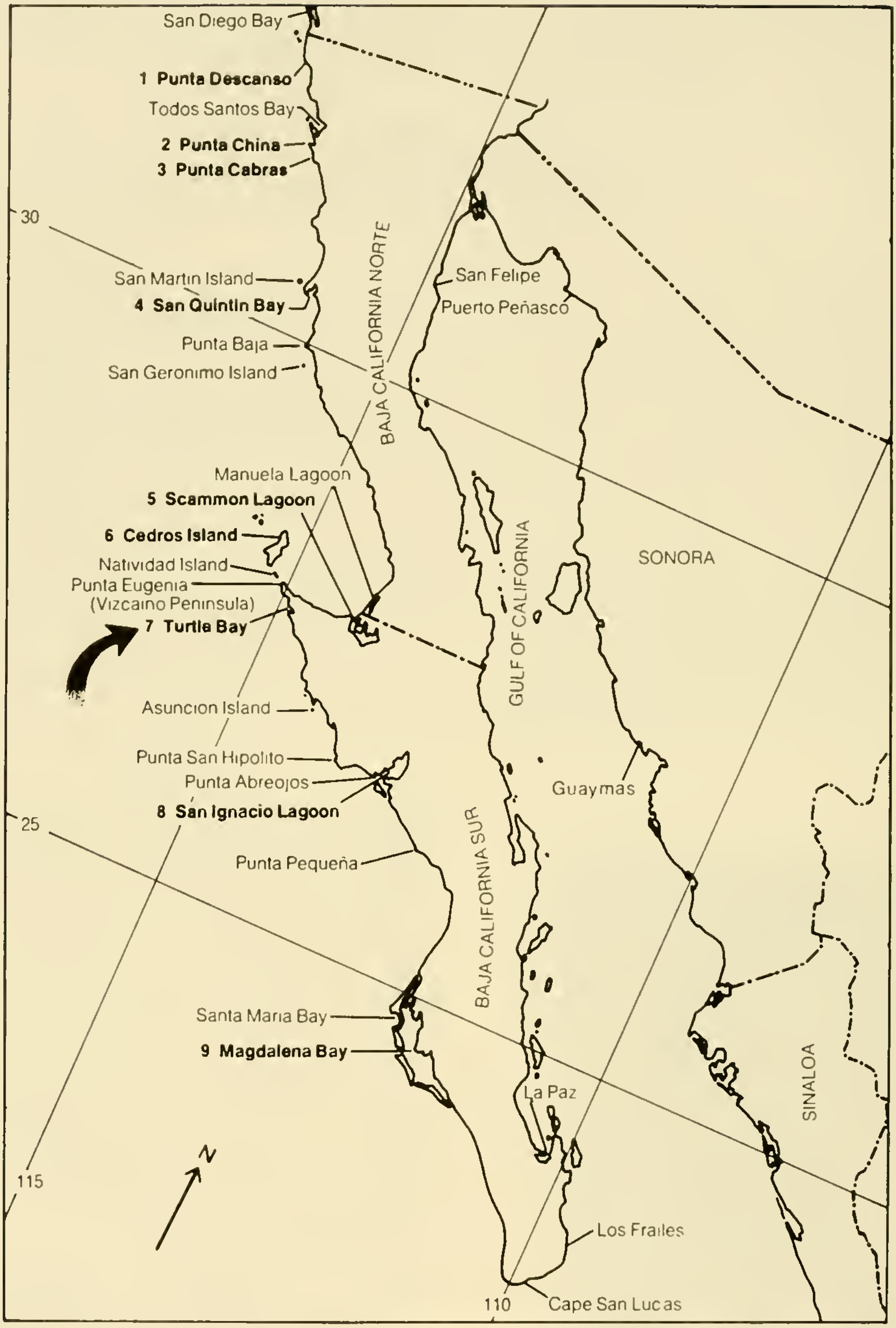

FIG. 1. *Index map of Baja California and the adjoining mainland of Mexico and the United States, showing the general location of Pleistocene localities (numbered 1-9) and the geographic localities representing the modern endpoints of range of some components of the Turtle Bay Pleistocene faunules (see text).*

Table 1. Pleistocene Faunal List, Turtle Bay

Symbols: F = fragmental preservation; J = juvenile specimens; M = many specimens; P = plate; PV = paired valves; S = spine; V = single valves; x = presence of one or more specimens

Mollusca	Collecting Stations						
Gastropoda	B-3027	B-3007	B-3050	B-3024	0624	B-3025	B-3048
Acanthina lugubris (Sowerby, 1822)	-	-	-	12	x	-	-
Acteocina cf. *A. carinata* (Carpenter, 1857)	-	1	-	14	-	-	-
Alia carinata (Hinds, 1844)	-	1	-	1	-	-	-
Anachis coronata forma *hannana* Hertlein and Strong, 1951	-	-	-	1	-	-	-
Astraea undosa (Wood, 1828)	1F	3	1F	4	x	-	4F
Bittium quadrifilatum Carpenter, 1864	-	7	-	-	-	-	-
Bulla punctulata A. Adams, 1850	-	-	-	1	-	-	-
Bursa californica (Hinds, 1843)	2F	-	-	-	x	-	3
Caecum crebricinctum Carpenter, 1864	-	2	-	-	-	-	-
Caecum dalli Bartsch, 1920	-	2	-	M	-	-	-
Cancellaria cassidiformis Sowerby, 1832	-	-	-	12	x	-	-
Cantharus elegans (Griffith and Pidgeon, 1834)	-	-	-	2	x[6]	-	-
Cerithium maculosum Kiener, 1841	-	-	-	3	-	-	-
Collisella limatula (Carpenter, 1864)	-	-	-	4	-	-	-
Columbella major Sowerby, 1832	-	-	-	1	-	-	-
Conus californicus Hinds, 1844	4	2F	-	4	x	-	-
Conus fergusoni Sowerby, 1873	-	-	1	4	x	-	-
Conus perplexus Sowerby, 1857	-	-	-	7	x	-	-
Conus purpurascens Sowerby, 1833	-	-	-	-	x	-	-
Conus regularis Sowerby, 1833	-	1F	-	-	-	2	-
Crepidula onyx Sowerby, 1824	2	-	-	-	x	-	1
Crucibulum scutellatum (Wood, 1828)	-	-	-	1	x	-	-
Crucibulum spinosum (Sowerby, 1824)	-	-	-	8	x	-	-
Cypraea annettae annettae Dall, 1909	-	-	-	-	x	-	-
Cypraea arabicula (Lamarck, 1811)	-	-	-	-	x	-	-

	B-3027	B-3007	B-3050	B-3024	O-624	B-3025	B-3048
Cypraea spadicea Swainson, 1823	-	2F	-	3	-	-	1
Diodora digueti (Mabille, 1895)	1	-	-	-	-	-	-
Elephantulum carpenteri (Bartsch, 1920)	-	-	-	3	-	-	-
Eupleura muriciformis (Broderip, 1833)	-	-	-	2	x[1]	-	-
Fartulum occidentale Bartsch, 1920	-	2	-	2	-	-	-
Fissurella volcano Reeve, 1849	3	6	-	5	-	-	1
Haliotis fulgens Philippi, 1845	-	-	-	1	-	-	-
Hipponix antiquatus (Linné, 1767)	2	-	-	-	x	-	-
Hipponix tumens Carpenter, 1865	-	-	-	6	-	-	-
Hormospira maculosa (Sowerby, 1834)	-	-	-	3	x	-	-
Kelletia kelletii (Forbes, 1852)	3	-	-	-	-	2	-
Lottia gigantea (Sowerby, 1834)	5	-	-	5	x	1	-
Macron aethiops (Reeve, 1847)	3J	2J	-	1J	x	-	-
Megasurcula carpenteriana (Gabb, 1865)	2	-	-	-	-	-	-
Mitra idae Melville, 1893	1	-	-	-	-	-	-
Nassarius tegula (Reeve, 1853)	-	-	-	M	x	-	-
Nerita scabricosta Lamarck, 1822	-	-	-	2	-	-	-
Neverita reclusiana (Deshayes, 1839)	MF	-	2	22	x	-	-
Norrisia norrisi (Sowerby, 1838)	1F	5	-	-	-	-	-
Oliva incrassata Lightfoot, 1786	-	-	-	3	x	-	-
Oliva cf. *O. polpasta* Duclos, 1833	-	1F	-	-	-	1F	-
Oliva polpasta forma *davisae* Durham, 1950	-	-	-	3	x	11	-
Oliva sp. indet.	-	-	-	-	-	-	1F
Olivella biplicata (Sowerby, 1825)	8	2	-	M	x	2	-
Pedipes cf. *P. unisulcatus* Cooper, 1866	-	-	-	1	-	-	-
Phyllonotus erythrostomus (Swainson, 1831)	-	-	-	2	-	-	-
"*Polinices*" sp. indet.	-	3F	-	-	-	-	-
Pseudomelatoma penicillata (Carpenter, 1865)	-	-	-	2	-	-	-
Pteropurpura festivo (Hinds, 1844)	-	1	-	4	x	-	-
Seila cf. *S. montereyensis* Bartsch, 1907	-	-	-	1F	-	-	-

	B-3027	B-3007	B-3050	B-3024	O-624	B-3025	B-3048
Serpulorbis squamigerus (Carpenter, 1857)	-	2F	-	-	-	-	-
Strombus gracilior Sowerby, 1825	-	-	-	1F	-	-	-
Strombus granulatus Swainson, 1822	-	-	-	-	x	-	-
Tegula aureatincta (Forbes, 1852)	-	1F	-	-	x[6]	-	-
Tegula eiseni Jordan, 1936	-	6	-	13	-	-	-
Tegula gallina (Forbes, 1852)	1	3	-	30	x	1F	2
Teinostoma cf. T. gallegosi Jordan, 1936	-	-	-	1	-	-	-
Terebra armillata Hinds, 1844	-	-	-	13	x	-	-
Thais biserialis (Blainville, 1832)	3	-	-	17	x	1	3
Triphora cf. T. pedroana (Bartsch, 1907)	-	-	-	1	-	-	-
Trivia solandri (Sowerby, 1832)	-	-	-	1	-	-	-
Trigonostoma goniostoma (Sowerby, 1832)	-	-	-	1	-	-	-
Truncatella californica Pfeiffer, 1857	-	-	-	1	x	-	-
Turbonilla sp. indet.	-	-	-	1	-	-	-
Turbo fluctuosus Wood, 1828	-	-	-	17	x	-	-
Vitularia salebrosa (King and Broderip, 1832)	-	-	-	-	x	-	-
Scaphopoda							
Dentalium neohexagonum Sharp and Pilsbry, 1897	5 .	-	-	-	-	-	-
Bivalvia							
Amiantis callosa (Conrad, 1837)	-	-	1V	1FV	-	-	-
Anomia peruviana d'Orbigny, 1846	-	1PV, 2V	2V	MV	x	-	-
Arcopsis solida (Sowerby, 1833)	-	-	-	-	x	-	-
Argopecten circularis circularis (Sowerby, 1835)	-	-	-	14V	x	-	-
Barbatia gradata (Broderip and Sowerby, 1829)	-	-	-	-	x	-	-
Barbatia reeveana (d'Orbigny, 1846)	-	-	-	-	x	-	-
Chaceia ovoidea (Gould, 1851)	-	1V	-	-	-	-	-
Chama sp. indet.	-	1 PV, 1V	-	-	-	-	-
Chione californiensis (Broderip, 1835)	-	3V	-	8PV	x	-	-
Chione cortezi (Carpenter, 1864)	-	-	4PV	-	-	-	-
Chione gnidia (Broderip and Sowerby, 1829)	-	-	-	8V	x	-	-

	B-3027	B-3007	B-3050	B-3024	O-624	B-3025	B-3048
Chione picta Willett, 1944	-	-	-	1V	-	-	-
Chione undatella (Sowerby, 1835)	2V	-	-	-	-	-	-
Corbula luteola Carpenter, 1864	-	2V	-	4V	-	-	-
Crassinella pacifica (C. B. Adams, 1852)	-	-	-	12V	?	-	-
Cryptomya californica (Conrad, 1837)	-	8V	-	2V	-	-	-
Diplodanta orbellus (Gould, 1851)	-	1V	-	-	x	-	-
Donax californicus Conrad, 1837	-	-	-	1PV	-	-	-
Dosinia ponderosa (Gray, 1838)	-	-	-	1V	-	-	-
Epilucina californica (Conrad, 1837)	-	1V	-	-	-	-	-
Felaniella sericata (Reeve, 1850)	-	-	-	25V	-	-	-
Glans subquadrata (Carpenter, 1864)	-	2V	-	-	-	-	-
Here excavata (Carpenter, 1837)	2PV	-	-	-	-	-	-
Hinnites giganteus (Gray, 1825)	4V	5V	-	-	-	-	-
Leporimetis obesa (Deshayes, 1855)	-	2PV	4PV	3PV, 12V	x	-	-
Lucinisca nuttalii Conrad, 1837	-	-	-	6V	x	-	-
Macoma indentata Carpenter, 1864	-	-	-	3PV, 4V	-	-	-
Macoma nasuta (Conrad, 1837)	-	1PV, 10V		-	-	-	-
Macoma nasuta forma kelseyi Dall, 1900	4V	-	-	-	-	-	-
Mactra cf. M. californica Conrad, 1837	1V	-	-	1JV	-	-	-
Megapitaria squalida (Sowerby, 1835)	-	-	-	4V	x	-	-
Milneria minima (Dall, 1871)	-	1V	-	-	-	-	-
Mytilus cf. M. californianus Conrad, 1837	-	-	-	-	-	-	1FV
Nuttallia nuttalii forma orcutti (Dall, 1921)	-	-	1V	-	-	-	-
Ostrea angelica Rochebrune, 1895	-	-	-	23V	x[2]	1V	-
Parvilucina approximata (Dall, 1901)	-	1V	-	-	-	-	-
Penitella fitchi Turner, 1955	-	-	-	-	x[3]	-	-
Penitella penita (Conrad, 1837)	1V	1V	-	-	-	-	-
Petricola carditoides (Conrad, 1837)	2PV	-	-	-	-	-	-
Protothaca grata (Say, 1831)	3V	2V	-	15V	x	-	4V
Pseudochama panamensis (? forma dalli Bernard, 1976)	-	-	-	2PV	x	-	-

	B-3027	B-3007	B-3050	B-3024	O-624	B-3025	B-3048
Saxidomus nuttalli (Conrad, 1837)	3V	2V	1V	1PV	-	1V	-
Semele decisa (Conrad, 1837)	-	-	-	1V	-	-	-
Semele flavescens (Gould, 1851)	-	-	-	1V	x	-	-
Tagelus californianus (Conrad, 1837)	-	-	-	2PV, 2V	-	-	-
Tellina bodegensis Hinds, 1845	2V	-	-	-	-	-	-
Tellina simulans C. B. Adams, 1852	-	-	-	2V	-	-	-
Tivela stultorum (Mawe, 1823)	6V	-	4V	-	-	1FV	1V
Trachycardium panamense (Sowerby, 1833)	-	22V	2JV	15V	x[4]	-	-
Trachycardium quadragenarium (Conrad, 1837)	1FV	-	-	-	-	-	-
Transennella tantilla (Gould, 1853)	-	2V	-	-	-	-	-
Tresus nuttallii (Conrad, 1837)	-	-	-	-	-	2FV	1V
Zirfaea pilsbryi Lowe, 1931	1V	-	2FV	-	-	-	-
Polyplacophora							
Stenoplax magdalenensis (Hinds, 1845)	-	-	-	-	1P	-	-
Bryozoa							
Caulloramphus spiniferum (Johnson, 1838)	-	x	-	x	-	-	-
Conopeum commensale Kirkpatrick and Metzelaar, 1923	-	x	-	x	-	-	-
Lagenipora punctulata (Gabb and Horn), 1862	-	x	-	-	-	-	-
Parasmittina crosslandi (Hastings, 1930)	-	-	-	x	-	-	-
Scrupocellaria bertholetti tenuirostris Osburn, 1950	-	-	-	x	-	-	-
Thalamoporella californica (Levinsen, 1909)	-	x	-	x	-	-	-
Watersipora cucullata (Busk, 1854)	-	-	-	x	-	-	-
Echinodermata							
Echinoidea							
Dendraster vizcainoensis Grant and Hertlein, 1938	-	-	-	-	-	-	2
Eucidaris thouarsi (Valenciennes, 1846)	-	1S	-	-	-	-	-
unidentified echinoid spines	-	-	-	14	-	-	-

	B-3027	B-3007	B-3050	B-3024	O-624	B-3025	B-3048
Arthropoda							
Cirripedia							
Balanus sp. indet.	-	1	-	1	-	1	-
Tetraclita squamosa rubescens (Darwin, 1854)	-	1	-	-	x	-	-
Ostracoda[5]							
Bairdia verdesensis LeRoy, 1943	-	-	-	2PV, 2V	-	-	-
Bradleya aurita (Skogsberg, 1928)	-	-	-	1PV, 1V	-	-	-
Cyprideis (Cyprideis) sp. indet.	-	-	-	1PV, 2V♂ 8PV, 8V♀	-	-	-
Cythereis glauca Skogsberg, 1928	-	-	-	1V	-	-	-
Leguminocythereis carrugata Benson, 1959	-	-	-	2V	-	-	-
Loxoconcha lenticulata LeRoy, 1943	-	-	-	2PV, 2V	-	-	-
Monoceratina sp. indet.	-	-	-	1V	-	-	-
Paracypris pacifica LeRoy, 1943	-	-	-	1V	-	-	-
Chordata (Fish)							
Clevelandia cf. C. ios (Jordan and Gilbert, 1882) (Otoliths)	-	-	-	5	-	-	-

Footnotes for Table 1

1. Identified as Eupleura triquetra (Reeve) by Chace (1956, p. 179).
2. Identified as Ostrea cumingiana Dunker by Chace (1956, p. 178).
3. Identified as "Pholad sp. (a fragment)" by Chace (1956, p. 178) = Penitella fitchi Turner, 1955, fide Kennedy (1974, p. 45).
4. Identified as Trachycardium procerum (Sowerby) by Chace (1956, p. 178).
5. Identified by E. C. Allison.
6. Present in C.A.S. loc. 34312 = 0624.

geology and collecting stations before his tragic and untimely death while on a geological reconnaissance in Sonora, Mexico, on January 1, 1971. I have attempted to complete these remaining sections largely on the basis of brief notes he had prepared for an outline of the manuscript, which were kindly forwarded to me by his wife, Eleanor. I would like to dedicate this paper, despite its obligated briefness, to the memory of Ned Allison, a close friend and a most valued colleague, for sadly Ned was not able to complete many of the projected studies which he had pursued with his characteristic vigor and enthusiasm.

Previous Work

Jordan and Hertlein (1926) briefly described the stratigraphy of the region and noted the presence of fossiliferous Pleistocene sands and gravels overlying the Tertiary beds of the area. They also recorded and described Pliocene megafossils, largely mollusks, from five localities in the general vicinity of Turtle Bay. Most of these collections were made by G Dallas Hanna in 1922, and by Hanna and Eric K. Jordan in 1925. Some of the Pliocene pectinids had been described in an earlier paper by Hertlein (1925). Hertlein (1933) later listed additional species of Pliocene mollusks and echinoids and reported the presence of Miocene diatomaceous shale, resulting from his field work at Turtle Bay in 1932.

Beal (1948, p. 80), in a geological reconnaissance of Baja California, cited Pliocene fossils, including mollusks, echinoids, and barnacles, from several localities near the bay, as well as listing the species previously reported by Jordan and Hertlein (1926). Chace (1956) recorded Pliocene and Pleistocene invertebrates, mostly mollusks, obtained by him in 1954, during a brief visit to Turtle Bay. He was the first to identify specifically Pleistocene metazoan fossils from this area and his records are included herein (Table 1). Minch, *et al.* (1976), in a review of the geology of the Vizcaino Peninsula, briefly described the terraces of the region and listed the Pleistocene fossils reported by Chace (1956) from Turtle Bay. Ortlieb (1979) summarized the status of his studies on the Quaternary marine terraces along the southwestern coast of Vizcaino Peninsula. He recorded the presence of fossiliferous terrace deposits of late Pleistocene age at elevations of approximately 5 and 12 meters in the vicinity of Turtle Bay. The fossils described herein were collected from some of these terrace deposits.

Topography

Turtle Bay (Figure 2) is nearly circular in shape with a diameter of about 2.5 miles (4 km.). Capelike rocky headlands with high bluffs border the entrance to the bay and they are separated by approximately a mile (1.6 km.) of mostly open water. Kelp Point (Punta Sargazo), with an elevation of 9 meters, forms the northwestern entrance to the bay and rises steeply towards Mount Bartolome (Monte Bartolomé, elevation 27 meters) to form a prominent headland to the west. Cape Tortolo (Cabo Tórtolo), a narrow promontory, attaining 127 meters in elevation, terminates as a rocky point about 6 meters high to form the southeastern entrance of the bay. A low reef extends from this peninsula northwesterly for a distance of nearly a mile (1.6 km.) to form a natural breakwater against the open sea. Southeast from Cape Tortolo, a rocky highland (Monte Belcher) borders the coast with sea cliffs of 8 to 15 meters in elevation and terminates two and one third miles (3.75 km.) southeastward of

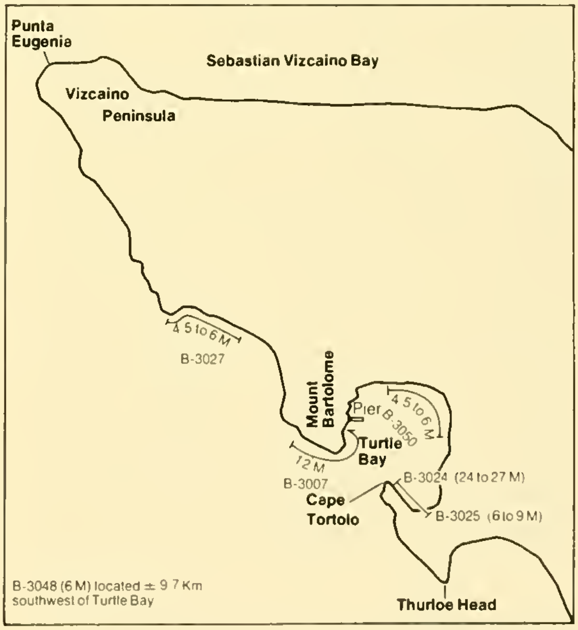

FIG. 2. *Sketch (not drawn to scale) showing the approximate location of the lowest emergent terrace remnants in the Turtle Bay area from which the Pleistocene fossils were collected (E. C. Allison ms.).*

the cape to form a bold headland known as Thurloe Head.

Northwest of the entrance of the bay, the coastline consists of rocky bluffs below the highland forming Mount Bartolome, to about 27°42′N. Here the cliffs give way to a sandy beach backed by a low plateau with an elevation of 5 to 7 meters that runs inland to the base of low hills.

Within the bay, the western shore fronting the highlands consists of high bluffs, whereas the northern and eastern sides of the bay possess low shingle and gravelly sand beaches, which gradually rise to higher broken country. The bay is shallow with depths at the entrance of 10 to 12 fathoms (18 to 22 m.) and shoals gradually toward the inner shore, where the three-fathom curve (5 m.) is about ¼ mile (0.16 km.) distant from the beach on the northeastern side. The bottom is composed largely of sand, but rocky substrates occur near the entrance of the bay. Beds of giant kelp *(Macrocystis)* are found along the open coast and within the entrance of the bay especially off Mount Bartolome (U. S. Navy Hydrographic chart 21081).

Geological Setting

In the region of the Vizcaino Peninsula, at elevations of a few meters to 250 meters, marine terraces mantle coastal rocks and are locally represented by eight or more separate depositional levels, ranging in age from late Pliocene to Pleistocene (Minch *et al.*, 1976). Faulted marine Pliocene (Almeja Formation), marine Miocene (Tortuga Formation) and late Cretaceous to late Jurassic rocks (Valle and Eugenia Formations) (see: Mina, 1957; Minch *et al.*, 1976) form the bedrock platform on which the terrace sediments were deposited (formational nomenclature after Kilmer, 1977). Regionally, the fossiliferous terrace sediments vary in thickness from thin veneers to beds of 7 or more meters and commonly include medium to coarse grained, olive-gray litharenite, interbedded with pebble and cobble conglomerate (Minch *et al.*, 1976).

In the vicinity of Turtle Bay, the marine Pleistocene is distributed in a series of fossiliferous shoreline deposits preserved as remnants on platforms representing the lowest emergent terrace in the region. The terrace deposits are mostly horizontally bedded, but some terraces are deformed by folding or are tilted by faulting (McIntyre and Sheldon, 1957; Minch *et al.*, 1976.)

Dr. Allison believed (personal communication) the shoreline deposits from which the fossils were collected to represent a single high-stand of the sea. Post-depositional episodes of deformation were assumed by him to account largely for the present differences in the elevations of the terrace remnants. Reliable correlation of these deposits, however, is not likely to be achieved by traditional stratigraphical methods, owing to the fragmental preservation of the terraces and the complex tectonic history of the local area.

Terrace Faunules

More than 140 species of metazoan invertebrates, mostly mollusks, and one fish were collected by Dr. Allison from six localities in the vicinity of Turtle Bay (Figure 2). Of these, 129 were identified to the species-level. The species are listed quantitatively for each collecting station (UCMP localities B-3027; B-3007; B-3050; B-3024; B-3025; B-3048) in Table 1. The fossils are deposited in the Museum of Paleontology, University of California, Berkeley.

Additionally, the fossils reported from Turtle Bay by Chace (1956), totaling 54 species of metazoan invertebrates, are included in the faunal tabulation (Table 1, SDNHM locality 0624 [=UCMP locality B-3024]). Mr. Chace divided the collection he made at Turtle Bay in 1954 between the San Diego Natural History Museum and the California Academy of Sciences (SDNHM locality 0624 = CAS locality 34312; *teste* Barry Roth, 1977). Chace's published report (1956) apparently was based solely on the SDNHM collection.

The combined collections of Allison and Chace from the terrace sediments total 139 identified taxa, as follows: 122 mollusks, 7 bryozoans, 6 ostracods, 2 echinoids, 1 cirripedian and 1 fish.

The following review of species diversity of the collected samples and interpretations of the depositional ecology of the faunules is based largely on the molluscan constituents of the fauna. The six collecting stations are indicated on Figure 2 and the fossils are listed in Table 1 by stations.

Terrace sediments preserved at an elevation of 4.5 to 6 meters along the bluff facing the sandy beach on the southwest side of the peninsula

northwest of Turtle Bay yielded 30 identified molluscan taxa (B-3027). This essentially open coast assemblage suggests a mixture of shallow water, sand dwellers (*Olivella, Neverita, Macoma, Tivela, Tellina,* etc.) and rock dwellers (*Fissurella, Lottia, Tegula, Thais, Hinnites,* etc.), together with a deeper water element (*Dentalium, Megasurcula, Astraea, Bursa,* etc.). To the southeast on Kelp Point, the headland forming the northern entrance to Turtle Bay, fossils were collected from terrace sediments (B-3007) at an elevation of about 12 meters. The collection, totaling 39 species, includes shallow water and offshore elements of rocky substrates (*Astraea, Cypraea, Tegula, Fissurella, Hinnites, Norrisia*-an algal associate, etc.) and sandy substrates (*Oliva, Olivella, Cryptomya, Trachycardium,* etc.). This locality was only partially sheltered from the open sea on the southwestern coast of an apparently insular Mount Bartolome at the time of deposition. These assemblages (localities B-3027 and B-3007) contain only temperate-water indicators, as would be expected from largely unprotected coastal sites.

Along, the northeast side of Turtle Bay, a terrace is preserved at an elevation of 4.5 to 6 meters (B-3050). Only 12 species, all temperate water indicators, were collected from these "back-bay" sediments. These taxa are mostly shallow water inhabitants of sandy substrates (*Neverita, Amiantis, Chione, Leporimetis, Macoma, Protothaca, Trachycardium,* lucinids, etc.), with minor elements of boring (*Zirfaea*) and of attaching forms (*Anomia*). At the time of deposition, this locality received protection from a probable insular Mount Bartolome to the west and from the high land to the northeast (see Figure 2). The absence of warm-water indicators may reflect the small size of the sample, a restricted facies, or possible chronological differences.

A terrace extends for several hundred meters, at an elevation of 24 to 27 meters, along the inner bay side to Cape Tortolo, the peninsula forming the southern entrance to Turtle Bay. These sediments (B-3024 = 0624) are richly fossiliferous and yielded 84 species of mollusks and 1 echinoid, including nearly all of the species (Table 2, Pt. 1) now confined largely to subtropical and tropical waters. This assemblage is a mixture of sand dwellers (*Neverita, Nassarius, Terebra, Phyllonotus, Cancellaria, Argopecten, Chione, Felaniella, Leporimetis, Protothaca, Trachycardium,* lucinids, etc.) and rocky and sandy rubble dwellers (*Acanthina, Cypraea, Fissurella, Haliotis, Hipponix, Lottia, Collisella, Conus, Crucibulum, Tegula, Thais, Turbo, Vitularia, Ostrea*), and includes some offshore inhabitants. On the southeastern side of Cape Tortolo, a terrace (B-3025) is preserved at an elevation of 6 to 9 meters from which 12 species were collected, including several warm-water indicators. These molluscan taxa largely represent sandy botton inhabitants (*Oliva, Olivella, Leporimetis, Tivela, Tresus,* etc.) and some rock-gravel dwellers (*Kelletia, Lottia, Tegula,* etc.). Dr. Allison noted that this terrace appears to be tilted upward to the northwest in the direction of the Cape Tortolo locality (B-3024), and he suggested that these terraces may be coeval depositional features. Both of these localities at the time of deposition were situated along the protected shoreline of an insular Cape Tortolo and were partially sheltered from heavy seas by an insular Mount Bartolome to the northwest and a most likely insular Mount Belcher to the southeast.

Approximately six miles (9.7 km.) southwest of Turtle Bay, another terrace (B-3048), at an elevation of about 6 meters, extends along the coastline and faces a long sandy beach. From these terrace sediments, 12 species were collected (*Astraea, Bursa, Fissurella, Crepidula, Tegula, Thais, Protothaca, Tivela, Dendraster,* etc.), suggesting sandy and rocky habitats in shallow water to offshore depths. All are temperate indicators, as would be expected from an exposed coastal site.

Inasmuch as nearly all of the warmer water indicators occur in the tilted, higher terraces (B-3024 - B-3025), these assemblages may have been deposited by an earlier high stand of the sea than those on the other, lower terrace remnants. The available paleontological evidence can not be used with confidence to establish the chronology of these depositional features.

Modern Biota of Turtle Bay

During the winter of 1974, Brusca (1975) undertook a survey of the marine biota of Turtle Bay based on 13 collecting stations representing

Table 2, Part 1. Southern Faunal Element of Turtle Bay

Species whose modern endpoints of range lie mainly to the south of Turtle Bay with occurrences in other late Pleistocene faunas of California and Pacific Baja California and with present geographic ranges indicated.

Mollusca	California: Los Angeles Basin: Terraces 2–13 Palos Verdes Hills	Terrace 1 Palos Verdes sand,	Palos Verdes sand, (Sensu Lato)	San Diego Area: Bay Point Formation (Sensu Lato)	Mexico: West Coast of Baja California: Punta Descanso[15]	Punta China[16]	Punta Cabras[17]	San Quintin Bay[18]	Scammon Lagoon[19]	Cedros Island[20]	San Ignacio Lagoon[20]	Magdalena Bay[21]	Modern Geographic Range After Keen, 1971, unless otherwise noted. * = Modern Range includes latitude of Turtle Bay
Gastropoda													
*Acanthina lugubris	x[1]	-	x[7,33]	x[12,23]	x	x	x	x	-	x	-	x	Todos Santas Bay[16] to Magdalena Bay, Baja California[42]
*Anachis coronata (+ forma hannana)	-	-	-	x[8,9,10]	-	-	-	-	x	-	x	x	Scammon Lagoon, Baja California to Ecuador[9]
Bulla punctulata	-	x[3]	x[3,4,5,7,33]	-	-	-	-	x[35]	x	-	x	x	Magdalena Bay, Baja California to Ecuador[27]
Cancellaria cassidiformis	-	-	-	-	-	-	-	-	-	-	-	x	Ballenas Bay, Baja California[45] to Peru
Cantharus elegans	-	-	-	-	-	-	-	-	-	-	x	x	Punta Abreojos, Baja California[45] to Peru
Cerithium maculosum	-	-	-	-	-	-	-	-	-	-	-	x	Magdalena Bay, Baja California to Santa Elena, Ecuador[45]
Columbella major	-	-	-	-	-	-	-	-	?	-	?	x	Santa Maria Bay, Baja California[45] to Peru[22]
*Conus fergusoni	-	-	-	-	-	-	-	-	-	-	-	x	Turtle Bay, Baja California to Peru[25]
Conus perplexus	-	-	-	-	-	-	-	-	-	-	-	x	Punta Pequeña, Baja California[45] to Peru[25]
Conus purpuroscens	-	-	-	-	-	-	-	-	-	-	-	x	Santa Maria Bay, Baja California[45] to Peru[25]
Conus reguloris	-	-	-	-	-	-	-	-	?[41]	-	-	-	Magdalena Bay, Baja Califórnio to Ecuador
*Crucibulum scutellatum	-	-	-	-	-	-	-	-	x	-	x	x	Cedros Island, Baja California[22] to Peru[45]
Cypraea annettae s.s.	-	-	-	-	-	-	-	-	-	-	-	x	Los Frailes, Baja California[45] to Puerto Peñosco, Sonora[23]
Cypraea arabicula	-	-	-	-	-	-	-	-	-	-	-	x	Punta San Hipolito, Baja California[19] to Peru
Diodora digueti	-	-	x[3,6,7]	x[10]	-	-	-	-	-	-	-	?	Scammon Lagoon, Baja California[26] to Ecuador
*Eupleura muriciformis	-	x[3]	x[3,7]	x[3,9,10,11]	-	-	-	-	-	-	x	x	Cedros Island, Baja California to Peru[27]
Hormospira maculosa	-	-	-	-	-	-	-	-	x	-	x	x	Santa Maria Bay, Baja California[45] to Ecuador[27]
*Macron aethiops	-	x[3]	x[13]	-	-	-	-	x	x	-	x	x	15 mi. N. of San Quintin Bay to Punta Pequeña, Baja California[45]
Nerita scabricosta	-	-	-	-	-	-	-	-	-	-	x	x	Punta Pequeña, Baja California[45] to Ecuador
Oliva incrassata	-	-	-	-	-	-	-	-	-	-	x	x	San Ignacio Lagoon, Baja California[45] to Peru
Oliva polpasta (+ forma davisae)	-	-	-	-	-	-	-	-	-	-	x	x	Magdalena Bay, Baja California to Peru
Phyllonotus erythrostomus	-	-	-	-	-	-	-	x	-	-	x	x	10 mi. NE of Cape San Lucas, Baja California[45] to Peru
Strombus gracilior	-	-	-	-	-	-	-	-	-	-	x	x	Magdalena Bay, Baja California[45] to Peru[29]
Strombus granulatus	-	-	-	-	-	-	-	-	-	-	-	x	Magdalena Bay, Baja California to Ecuador[29]
*Terebra armillata	-	-	-	-	-	-	-	x[37]	-	-	-	x	off Scammon Lagoon, Baja California[26] to Peru
*Thais biserialis	-	x[1]	x[1,5,7,33]	-	x	x	x	-	x	x	x	x	Santa Maria Bay, Baja California[45] to Chile
Trigonostoma goniostoma	-	-	-	-	-	-	-	-	-	-	-	x	Puerto Peñasco, Sonora[26] to Panama
*Turbo fluctuosus	-	-	-	-	-	-	-	-	x	-	x	x	Cedros Island, Baja California to Peru

	Terraces 2–13 Palos Verdes Hills	Terrace 1 Palos Verdes sand,	Palos Verdes sand, (Sensu Lato)	Bay Point Formation (Sensu Lato)	Punta Descanso[15]	Punta China[16]	Punta Cabras[17]	San Quintin Bay[18]	Scammon Lagoon[19]	Cedros Island 20	San Ignacio Lagoon[20]	Magdalena Bay[21]	
•Vituloria salebrosa	-	-	-	-	-	-	-	-	-	-	-	-	Cedros Island, Baja California to Guaymas, Sonora and to Colombia
Bivalvia													
Arcopsis solida	-	-	-	-	-	-	-	-	-	-	-	x	Asuncion Island, Baja California to Peru[30]
•Argopecten circularis s.s.	-	?	?	x[8,9,10]	-	-	-	-	-	?	?	?	Cedros Island, Baja California to Peru
•Barbatia gradata	-	-	-	-	-	-	-	-	-	-	-	x	Scammon Lagoon, Baja California to Peru
•Barbatia reeveana	-	-	-	-	-	-	-	-	-	-	-	-	Manuela Lagoon, Baja California to Peru
Chione cortezi	-	-	x[7]	x[10]	?	-	-	-	?	-	?	?	near Magdalena Bay, Baja California to Guyamas, Sonora
•Chione gnidia	-	x[1,3]	x[4,7,33]	x[8,9,10,11]	-	-	-	-	-	-	x	x	Cedros Island, Baja California to Peru
Chione picta	x[2]	x[1]	x[7,33]	x[23]	x	-	-	x[37]	-	-	x	x	Magdalena Bay, Baja California[22] to Peru[32]
•Crassinella pacifica (= C. branneri Arnold)	-	x[1]	x[1,3,4,5,7,49]	x[1,3,11,14,35]	-	-	-	x[49]	-	-	-	x[49]	Laguna Beach, California[49] to Peru
•Dosinia ponderosa	-	x[1]	x[1,3,4,7,33]	x[1,3]	-	-	-	x	-	-	-	x	Scammon Lagoon, Baja California to Peru
•Megapitaria squalida	-	-	x[4,6,7]	-	-	-	-	x	x	-	x	x	Scammon Lagoon, Baja California to Peru
Ostrea angelica	-	-	-	x[10]	-	-	-	-	-	-	-	?	San Ignacio Lagoon, Baja California to Peru
•Protothaca grata	-	-	x[7]	-	-	-	-	-	-	-	-	x	Cape Colnett, Baja California to Chile
Semele flavescens	-	-	-	-	-	-	-	-	-	-	-	x	Magdalena Bay, Baja California to Peru[32]
•Tellina simulans	-	?	?	-	-	-	-	-	-	-	x[31]	x[31]	Scammon Lagoon, Baja California to Peru
Trachycardium panamense (=T. procerum auct. not Sowerby)	-	x[1,3]	x[4,5,6,7,33]	x[10,11]	-	-	-	?	?	-	?	?	San Ignacio Lagoon, Baja California to Costa Rica
Polyplacophora													
•Stenoplax magdalenensis (=acrior Pilsbry)	x[2,24]	-	x[24,33]	x[23,24]	x	-	-	-	-	-	-	x	Cedros Island, Baja California[22] to Guaymas, Sinaloa[45]
Echinodermata													
Echinoidea													
•Dendraster vizcainoensis (+D. v. similaris)	-	-	x[7,28]	-	-	-	-	x[28]	-	x[28]	-	?	off Scammon Lagoon[26], to ? Punta Eugenia, Baja California
Eucidaris thouarsii	-	-	-	-	-	-	-	-	-	-	-	-	Cape San Lucas, Baja California to Ecuador[28]; Guadalupe Island, Baja California[50]

intertidal and subtidal habitats. He reports (Brusca. *in litt.*, 1978) the coldest water temperatures near the mouth of the bay, where isolated stands of giant kelp (*Macrocystis*) occur, together with algal associations characteristic of cool water. He found temperatures to increase gradually within the bay, with warm temperate and tropical organisms (Panamic species) living in the warmer backwaters. In a summary of his study, Brusca (1975) concluded that "tropical species" (39%) outnumbered "temperate species" (21%) in the samples, although he noted (*in litt.*, 1978) that the temperate organisms dominated tropical ones in terms of total biomass (see also Brusca and Wallerstein, 1979, p. 76).

The mollusks, on the other hand, are predominately wide-ranging eurytopic species, with the Panamic element represented by a minor constituency. The presence of severe coastal upwelling of cold water in the area

Table 2, Part 2. Northern Faunal Element of Turtle Bay

Species whose modern endpoints of range lie mainly to the north of Turtle Bay with occurrences in other late Pleistocene faunas of California and Pacific Baja California and with present geographic ranges indicated.

	California				Mexico								Modern Geographic Range After McLeon, 1978, unless otherwise noted
	Los Angeles Basin			San Diego Area	West Coast of Baja California								* = Modern Range includes latitude of Turtle Bay
Mallusca Gastropoda	Terraces 2-13 Palos Verdes Hills	Terrace 1 Palos Verdes sand	Palos Verdes sand, (Sensu Lato)	Bay Point Formation (Sensu Lato)	Punta Descanso[15]	Punta China[16]	Punta Cabras[17]	San Quintin Bay[18]	Scammon Lagoon[19]	Cedros Island[20]	San Ignacio Lagoon[21]	Magdalena Bay[22]	
*Alia carinata	x[1]	x[1,3]	x[3,5,7,33,46]	x[9,11,14]	x	x	x	x[35]	-	-	x	x	Baranof Island, Alaska to San Francisco Island (Gulf of California)[45]
*Astraea undosa	x[2]	x[1,3]	x[7,33,45]	x[12,14,23]	-	x	-	x	-	-	-	x	Avila Beach, California to Punta Pequeño, Baja California[45]
*Bittium quadrifilatum	-	x[3]	x[3,7]	-	x	x	-	x	-	-	-	-	San Pedro, California to Santa Maria Bay, Baja California
*Caecum dalli [= + C. licatum Bartsch, 1920]	x[2]	-	-	-	x	-	-	x	-	-	-	-	SE of Farallon Islands, California[45] to Asuncion Island, Baja California
*Caecum crebicinctum	x[1]	x[1,3]	x[3]	x[10]	-	-	-	x	-	-	-	-	Hesketh Island, Alaska to Los Cruces, Baja California (Gulf of California)[45]
*Callisella limatula	x[2]	?[1]	x[5,7]	x[10,12]	-	-	-	x[47]	-	-	-	-	Newport, Oregon to Punta Abreojos, Baja California[45]
*Conus californicus	x[1,2]	x[1,3]	x[3,4,7,46]	x[9,11,12,14]	x	x	x	x	-	x	-	x	Farallon Islands, California to Magdalena Bay, Baja California
Cypraea spadicea	x[1,2]	x[1,3]	x[7,46]	x[14,23]	x	x	-	-	-	-	-	-	Monterey Bay to Cedros Island, Baja California
*Fartulum occidentale [= + F. bakeri Bartsch, 1920]	x[1,2]	x[1]	x[5,7,33,46]	x[11,14]	x	-	-	x	-	-	-	x	Yukon Island, Alaska to Magdalena Bay, Baja California[45]
*Fissurella volcano	x[1,2]	x[3]	x[3,7]	x[3,6,12,23]	x	x	x	x	-	x	-	x	Cresent City, California to Magdalena Bay, Baja California
*Haliotis fulgens	-	x[3]	x[7]	x[3,11]	-	-	-	x	-	-	-	x	Point Conception, California to Magdalena Bay, Baja California
*Hipponix tumens	x[2]	x[1]	x[3,7,33]	x[3,6,9,12,23]	x	x	x	x	-	-	-	x	Crescent City, California to Magdalena Bay, Baja California
*Kelletia kelletii	-	x[1,3]	x[3,5,6,7,33]	x[3,14,23]	x	x	x	x	-	-	-	x	Tajiguas, Santa Barbara Co., California[45], to Asuncion Island, Baja California
*Lortia gigantea	-	-	x[7]	x[9,11]	x	x	-	-	-	x	-	x	Neah Bay, Washington to Turtle Bay, Baja California
*Megasurcula carpenteriana	-	x[3]	x[5,7,33]	x[3,11,14]	x	-	-	x[37]	-	-	-	x	Bodega Bay, California[34] to San Cristobal, Baja California[45]
*Mitra idae (= +M. catalinae Dall, 1919)	x[1,2]	x[3]	x[7,33,46]	x[12,14]	x	-	-	x	-	-	-	-	Crescent City, California[34] to Punta San Pablo, Baja California[45]
*Nassarius tegula	-	x[1,3]	x[3,4,5,6,7,33]	x[8,11]	-	-	-	x	-	-	x	x	Long Beach, California to San Ignacio Lagoon, Baja California[43]
*Norrisia norrisi	x[2]	x[3]	x[3,6,7,33,46]	x[3,10,11,12,14]	-	-	-	x	-	x	-	x	Point Conception, California to Asuncion Island, Baja California
*Olivella biplicata	x[1,2]	x[2,3]	x[3,4,5,6,7,33,46]	x[9,11,12,14]	x	x	x	x	-	-	-	x	Vancouver Island, Canada to Turtle Bay, Baja California[45]
*Pseudomelatoma penicillata	-	?[3]	?[5,7,33]	-	-	-	?	?	-	-	x	x	Santa Barbara, California to Magdalena Bay, Baja California
*Pteropurpura festiva	x[1]	x[1,3]	x[3,4,5,7,33]	x[11,14]	x	x	-	x	-	-	-	x	SE Point Conception, California to Magdalena Bay, Baja California[45]

	Terraces 2-13 Palos Verdes Hills	Terrace 1 Palos Verdes sand	Palos Verdes sand, (Sensu Lato)	Bay Point Formation (Sensu Lato)	Punta Descanso[15]	Punta China[16]	Punta Cabras[17]	San Quintin Bay[18]	Scamman Lagoon[19]	Cedros Island[20]	San Ignacio Lagoon[21]	Magdalena Bay[22]	
•Saila montereyensis	x[1]	-	x[5,7,33]	x[11,14]	x	x	x	x	-	-	-	-	SE Farallon Islands, California, to Punta San Pablo, Baja California[45]
•Tegula aureotincta	x[1]	x[1,3]	x[5,7,33, 46]	x[11,12,14]	x	-	-	x	-	x	x	x	Rincon Point, Santa Barbara Co., California to Magdalena Bay, Baja California[45]
•Tegula eiseni (= T. ligulata auct. not Menke, 1850)	x[1,2]	x[1,3]	x[3,4,5,7, 33]	x[10,11,14,23]	x	-	x	x	-	-	-	x	SE Point Mugu, Ventura Co., California to Magdalena Bay, Baja California
•Tegula gallina	x[1]	x[1,3]	x[3,5,7,33]	x[3,23]	x	-	x	-	-	x	-	x	Santa Cruz Island, California to ? Magdalena Bay, Baja California[45]
•Triphora pedroana	x[1,2]	x[1]	x[7,33]	x[10]	x	x	-	x	-	-	-	x	Pacific Grove, California to Magdalena Bay, Baja California[45]
•Truncatella californica	x[1]	-	-	x[11]	-	-	-	x	-	-	-	-	Palos Verdes Peninsula, California[45] to Magdalena Bay, Baja California[44]
Bivalvia													
•Amiantis callosa	-	x[1,3]	x[3,4,5,6, 7,33]	x[3,11]	x	-	-	x	-	-	-	x	Santa Barbara, California to Cape San Lucas, Baja California [45]
•Chaceia ovoidea	-	x[39]	x[39,46]	x[39]	-	-	-	-	-	-	-	-	Santa Cruz, California to Turtle Bay, Baja California
•Corbula luteola	x[1]	x[3]	x[3,5,7, 33]	x[8,9,10, 11,14]	x	-	-	x	-	-	x	x	Monterey, California to La Paz, Baja California[40]
•Donax californicus	-	x[3]	x[4,5,6, 11]	x[9,10,11]	-	-	-	x	-	-	x	x	Goleta, California to Magdalena Bay, Baja California[40]
•Epilucina californica	x[1,2]	x[1,3]	x[3,5,7, 33]	x[3,11,14 23]	x	-	-	x	-	x	-	-	Cresent City, California to San Ignacio Lagoon, Baja California[40]
Glans subquadrata	x[1,2]	x[1,3]	x[5,6,7]	x[11,12,14, 23]	x	-	-	x	-	-	-	x	Queen Charlotte Islands, Canada to Punta Rompiente, Baja California[36]
•Hinnites giganteus	x[2]	x[3]	x[3,4,5,6, 7,46]	x[12]	x	x	-	x	-	-	-	x	Aleutian Islands, Alaska to Magdalena Bay, Baja California[40]
•Macoma nasuta (+forma kelseyi)	-	x[3]	x[3,4,5, 7,33]	x[11,14]	x	-	x	x	-	-	x	x	Kodiak Island, Alaska to Cape San Lucas, Baja California[38]
Milneria minima	cf[2]	-	-	-	-	-	-	-	-	-	-	-	Monterey, California to Natividad Island, Baja California[36]
•Nuttalia nuttalii (+ forma orcutti)	-	x[3]	x[3,4,7]	-	x	-	-	x	-	-	-	x	Bodega Bay, California to Magdalena Bay, Baja California
•Penitella fitchi	-	-	x[39]	-	-	-	-	-	-	-	-	-	Monterey Bay, California[48] to Punta Pequeña, Baja California[39]
•Penitella penita	-	x[39]	x[39]	x[39]	x[39]	-	x	-	-	-	-	-	Gulf of Alaska to Punta Pequeña, Baja California[39]
Saxidomus nuttalli	-	x[3]	x[3,4,5,7, 33]	x[3,12,14]	x	-	x	x	-	-	-	x	Humboldt Bay, California to San Geronimo Island, Baja California
•Semele decisa	cf[2]	x[3]	x[3,4,5,6, 7,33]	x[11,12,14, 33]	-	x	x	x	-	-	x	x	Santa Barbara, California to Cape San Lucas, Baja California
•Tellina bodegensis	-	x[3]	x[3,7]	x[8,9,11,14]	x	-	x	x	-	-	-	x	Queen Charlotte Islands, Canada to Cape San Lucas, Baja California[40]
•Tivela stultorum	-	x[3]	x[3,4,5,7]	x[3,11,14,23]	x	-	x	x	-	-	-	x	Stinson Beach, Marin County, California to Magdalena Bay, Baja California[40]
•Trachycardium quadragenarium	x[1]	x[1,3]	x[3, 7,33]	x[3,11,14,23]	x	-	x	x	-	-	-	-	Monterey, California[40] to Cape San Lucas, Baja California[38]
•Transennella tantilla	x[2]	x[3]	x[3,5,33]	x[8,11,14,46]	x	x	x	x	-	-	-	-	Sitka Harbor, Alaska to Baja California (L.27° N)[40]
•Zirfaea pilsbryi	-	x[3,39]	x[3,7,39]	x[10,14,39]	-	-	x	-	-	-	-	-	Arctic Alaska to Magdalena Bay, Baja California[39]

Footnotes to Table 2

1. Woodring, et al., 1946
2. Marincovich, 1976
3. Arnold, 1903
4. Delong, 1941
5. Willett, 1937
6. Bruff, 1946
7. Kanakoff and Emerson, 1959
8. Kern, 1971
9. Kern, et al., 1971
10. Emerson and Chace, 1959
11. Hertlein and Grant, 1944
12. Webb, 1937
13. Valentine, 1961
14. Emerson and Addicott, 1953
15. Valentine, 1957
16. Emerson, 1956 b
17. Addicott and Emerson, 1959
18. Jordan, 1926
19. Jordan, 1924
20. Hertlein, 1934
21. Jordan, 1936
22. Keen, 1971
23. Valentine, 1960 a
24. Berry, 1922
25. Hanna, 1963
26. Collection of the American Museum of Natural History
27. Hertlein and Strong, 1955
28. Grant and Hertlein, 1938
29. Emerson and Old, 1963
30. Hertlein and Strong, 1943
31. Hertlein and Strong, 1949
32. Olsson, 1961
33. Valentine, 1956
34. McLean, 1978
35. Valentine and Meade, 1961
36. Coan, 1977
37. Monger, 1934
38. Fitch, 1953
39. Kennedy, 1974
40. Hertlein and Grant, 1972
41. Hanna, 1963, p. 26, records two specimens identified as *Conus gradatus* (which may be refereable to the present species) from the Pleistocene at Punta Santa Rosalia, about 60 miles northeast of Scammon Lagoon.
42. Closely related, if not conspecific taxa (*A. angelica* and *A. tyrianthina*), occur in the Gulf of California as far south as San Carlos Bay, Guaymas.[45]
43. Replaced southward and within the Gulf of California by *N. tiarula* (Kiener, 1841), which some workers consider to be southern populations of this species.
44. This taxon is apparently conspecific with *T. bairdiana* C. B. Adams, 1852, for which two lots are known from the northern part of the Gulf of California and one lot from Tabogo Island, Panama, *teste* J. H. McLean.
45. *teste* J. H. McLean, based on the collection of the Los Angeles County Museum of Natural History.
46. Addicott, 1964
47. Valentine, 1960 b
48. Haderlie, 1979
49. Coan, 1979
50. Fitch, 1962

(seasonally, from April through July, according to Blackburn, 1969) accounts for the shallow water occurrences of temperate organisms, including the luxuriant growth of kelp beds in this region (Dawson, *et al.*, 1960). The diverse thermal regime of the hydroclimate of this coast is also supportive of subtropical and tropical organisms, especially in protected habitats such as shallow bays and lagoons, where the effects of solar radiation and sluggish circulation locally influence water temperatures (Emerson, 1956, a, b; Brusca and Wallerstein, 1979). Within the confines of Turtle Bay, these contrasting faunal elements are represented by mollusks associated with kelp beds (*Astraea undosa, Norrisia norrisi, Haliotis* spp., and other temperate species) and by subtropical and tropical species (*Bursa caelata, Pteria sterna, Crepidula striolata,* and others) living together with the more numerous ubiquitous species, some of which range from Alaska to Peru.

The ranges of the shelled mollusks living on the continental shelf of the northeastern Pacific Ocean have been investigated by computer techniques and other numerical methods in an attempt to define zoogeographic provinces on the basis of the latitudinal distribution of this major faunal constituent (Stanton and Dodd, 1970; Addicott, 1966; Valentine, 1961, 1966; Hall, 1964; for a general summary see Brusca and Wallerstein, 1979:72-77). Distributional boundaries are defined as provincial boundaries and apparently reflect the regional hydroclimatic patterns controlling temperature regimes and governing other hydrographic conditions on the shelf.

Turtle Bay (27°14′N.) is geographically situated near the northern limit of the subtropical Surian Province, which extends southward along the western coast of Baja California from Punta Eugenia (28°15′N.) to Cape San Lucas (22°52′N.). In the region of the Cape, this province borders on the extensive, tropical Panamic Province,

which includes the Gulf of California and terminates in northern Peru. The Surian Province borders on the north with the warm temperate, Californian Province, which ends near Point Conception, California (34°50′N.), the southern boundary of the temperate Oregonian Province, which extends northward to Dixon Entrance, British Columbia (54°25′N.), where it is replaced by the cool temperate Aleutian Province.

Late Pleistocene faunal provinces also have been defined for the molluscan assemblages preserved in sediments on the lowest emergent marine terraces of western Baja California to Washington (Valentine, 1961; Addicott, 1966; Kennedy, M. S.). Valentine (1961, p. 393) proposed the Magdalenan Province, extending southward from Punta Eugenia to Cape San Lucas on the west coast of Baja California, as a late Pleistocene province characterized by faunas chiefly Panamanian in aspect. The northern boundary of the late Pleistocene Magdalenan Province was questionably placed by Addicott (1966) to coincide with the northern limits of the modern Surian Province (Punta Eugenia), owing to the meager documentation of the Pleistocene terrace fauna of this region of Baja California. The faunistic data recorded in this report for the Turtle Bay Pleistocene assemblages, therefore, provide additional paleodistributional evidence for more adequately defining this provincial boundary.

The presence of a prominent Panamic faunal component in two of the Turtle Bay faunules (UCMP localities B-3024; B-3025) confirms the assignment of these assemblages to the Magdalenan Province. A reliable provincial assignment of the remaining Turtle Bay assemblages requires a better understanding of the late Pleistocene chronology of the terrace sequence in the Turtle Bay area.

Faunal Composition and Comparisons

All of the identified fossils from the seven localities (Table 1) represent living species. The composition of the mollusk and echinoid collection is dominated by taxa whose modern endpoints of range lie mainly to the north or to the south of Turtle Bay. These predominantly southern and northern faunal components are enumerated in Table 2, Parts 1 and 2, respectively, together with the known modern geographic ranges and the reported occurrences in selected late Pleistocene faunas of southern California and western Baja California. Of the identified mollusks (122 species) and echinoids (2 species), the southern and northern elements are about equally represented (38 and 39% respectively) and they constitute slightly more than three quarters (77%) of the mollusk-echinoid collected fauna. The remaining molluscan taxa (23%) represent a mostly eurythermal element, whose components now range widely, living to the north in boreal or cool temperate waters and extending southward, commonly at increasing depths, into subtropical or tropical waters. The modern ranges of 97 percent of the eurythermal and northern elements include the latitude of Turtle Bay. The present northern endpoints of range of 53 percent of the southern element, however, occur to the south of this latitude, but nearly all of these species (92%) now live south of Turtle Bay along Pacific Baja California, or in the region of Cape San Lucas. Most of the species of the southern element also occur in the Gulf of California and many range as far south as northern Peru. The two species (*Cypraea annettae* and *Phyllonotus erythrostomus*) not known to occur at the present time on the west coast of Baja California live in the Gulf of California and range southward to Panama or Peru. Only two species in the collection (*Macron aethiops* and *Dendraster vizcainoensis*), both members of the southern element, are restricted now in distribution to the west coast of Baja California, including the latitude of Turtle Bay, but they are known from late Pleistocene deposits as far north as the Los Angeles Basin (Table 2, Part 1).

Although all of the faunas cited in Table 2 are apparently late Pleistocene in age, absolute dates based on radiometric ages are available for only a few Pacific Coast terraces (summary in Ku and Kern, 1974). Faunistic interpretations, therefore, are limited largely to comparisons with physiographically similar deposits. Literature references (Table 2) to the geographic occurrences of terrace sediments in the Los Angeles and San Diego areas require elucidation. Woodring, *et al.* (1946) restricted the Palos Verdes Sand to the marine deposits on the lowest emergent terrace of the Palos Verdes Peninsula where they recognized 12 other higher terraces (numbered 2

to 13 in ascending order). Accordingly, the records of fossils from the older terraces (2 to 13) of the Palos Verdes Hills are listed separately from those of the lowest terrace, identified as "Terrace 1, Palos Verdes Sand." Records for other deposits in the Los Angeles Basin tentatively assigned to the Palos Verdes Sand (Kanakoff and Emerson, 1959) are listed under the heading, "Palos Verdes Sand, *Sensu Lato*." Records for the San Diego area include fossils presumed to be from sediments correlative with the Bay Point Formation (Valentine, 1959; Emerson and Chace, 1959; Kern, 1971; Kern, *et al.*, 1971). Kern (1977) recently demonstrated the presence of more than one marine terrace level at elevations previously thought to represent the abrasion platform cut during the high stand of the sea responsible for the Bay Point sediments. On the basis of available faunistic and physiographic evidence, however, all of these deposits are apparently referable to the late Pleistocene, and thus invite faunistic comparison within this limited temporal framework. In this context, the following paleogeographic interpretations of the Turtle Bay fauna are undertaken.

When the faunal elements of the Turtle Bay assemblages are compared with the constituents of most of the well-documented, late Pleistocene molluscan and echinoid faunas recorded from western Baja California and southern California, the southern element (subtropical and tropical species) is found to be well represented in the Magdalena Bay fauna (with 94 percent of the taxa definitely and questionably identified) and the northern element (temperate species) is also abundantly represented in the Los Angeles Basin (100%) and in the San Diego area (88%), see Table 2. In contrast, the southern element in the Magdalena faunules is less well represented in the Los Angeles Basin (36%) and in the San Diego area (26%), whereas the northern element in the Magdalena faunules is more completely represented in the longitudinally intermediate Pleistocene sites listed in Table 2, but most of these faunas represent open-coast depositional sites from which constituents of the southern faunal element would not be expected (Emerson, 1956b; Addicott and Emerson, 1959; Valentine, 1961; Addicott, 1966).

This is a late Pleistocene regional pattern of distribution in which the southern element (subtropical and tropical species) becomes progressively less prominent in deposits at increasingly higher latitudes. For the northern element (boreal and temperate species) this latitudinal trend is reversed (but not to the same magnitude). This distributional pattern is also reflected in the composition of the regional modern fauna, but with a diminution in the ratio of Panamic elements to Californian elements especially noticeable north of the Vizcaino Peninsula. The coexistence of numerous locally extinct southern and northern modern species in Pleistocene sediments, however, continues to be an enigma to the student of biogeography.

The terrace associations in which the extralimital southern and northern species coexist are termed "thermally anomalous," because thermal changes in the hydroclimate are presumed to be largely responsible for the shifting of ranges of taxa that have become geographically separated. The paleoclimatic significance of the thermally anomalous associations have been discussed by numerous workers, including Woodring, *et al.* (1946, p. 86-90), Emerson (1956 a; b, p. 326-327), Valentine (1955, p. 465-468; 1961, p. 393-400), Addicott (1966, p. C16-19), Kern (1971, p. 819-820; 1973, p. 26-33) and Zinsmeister (1974, 84-94). The generally accepted explanation of climatic expansion, in which isothermal shifts permit the local coexistence of thermally anomalous species by producing warmer "summer" water temperatures and at the same time intensifying upwelling of cooler coastal waters has been questioned by some workers. Kern *et al.* (1971, p. 337) succinctly summarized the major objections to climatic expansion: "The geographic ranges of these [northern species] and the extralimital [southern] species must involve more complex changes than simple warming or cooling. It must also be recognized that some of these species may have changed physiologically and ecologically since late Pleistocene times and some of these may be limited geographically by factors other than water temperature." Zinsmeister (1974, p. 84) offered a modified expansion hypothesis stating " . . . that some of these anomalies resulted from periodic local and temporary current changes that permitted the introduction of larvae of

tropical mollusks into areas of cooler water temperatures." He documented his thesis with records of incursions of subtropical and tropical elements into the waters of southern California during historical times. Such periodic incursions during warm years are of a brief duration (generally 2-3 years) and the short-term, surviving populations are not believed to be reproductively viable (Hubbs, 1948). This distributional mechanism alone seemingly would not account for the diversity of the tropical extralimital species (Kanakoff and Emerson, 1959, Table 2; Valentine and Meade, 1961, Table 10) found in the Pleistocene sediments, and could not account for the presence of most non-pelagic organisms.

However, as Kern (1973) and others have pointed out, the possibility of physiological and ecological adaptive changes in species can not be discounted, but such alterations of tolerances are difficult to document. An example of ecologically adaptive changes interpreted on the basis of shell morphology is inferred by Campbell and Valentine (1979) as a response to differing terrestrial temperatures during tidal exposures in Pleistocene *Nucella lamellosa*. Changes in temperature-distribution relationships in molluscan species in which shell morphology is not seemingly altered are more difficult to substantiate (Woodring, 1951). Stanton and Dodd (1970) and Kern (1973), for example, concluded that the bivalve genus *Dosinia*, long recognized as a warm-water indicator in the west coast Tertiary owing to its presence in the modern Surian and Panamic faunal provinces, had undergone a change in thermal requirements since the early Pliocene, where it occurs in assemblages dominated by cooler water indicators. Valentine and Meade (1961, p. 35) found isotopic temperatures yielded by Pleistocene specimens of *D. ponderosa* to be somewhat lower than expected for its modern thermal regime, and suggested that temperatures at which this species can deposit shell material were lower than those ". . . necessary at some other time in its life for some other function." In a study of the Pliocene San Diego Formation, Hertlein and Grant (1972, p. 38) described *D. ponderosa diegoana* as a new "subspecies" intermediate in shell characters between the early Pliocene *D. jacalitosana* and the living *D. ponderosa*, on which Kern (1973) based his interpretations of the thermal requirements of *D. jacalitosana* from the Pliocene of the Ventura Basin of California. *Dosinia ponderosa* is recorded from warmer late Pleistocene assemblages in the Los Angeles and San Diego area and southward (Table 2, Pt. 1), but is not known from the early Pleistocene assemblages of the Los Angeles Basin, which are generally interpreted as cool water faunas (Woodring, *et al.*, 1946). For this example, the evidence, though not complete, suggests that some species-groups within a genus may have higher thermal requirements for critical functions other than shell deposition, or the presence of discrete, but not easily detected morphological differences in shell characters, may reflect species-level evolution within temporally isolated populations of a lineage, rather than physiologically divergent species.

Occurrences of some extralimital species undoubtedly have resulted from factors other than climatic influences, but such inferences require rigid documentation. The recent discoveries of wide-ranging fluctuations of the Pleistocene marine climates during geologically brief periods of time, determined by isotopic records preserved in oceanic cores (see Shackleton and Opdyke, 1973; 1976), provides stronger support for the role of climatic expansion in explaining the extralimital species associations.

The available paleontological data suggests that a northward latitudinal shift of about 3 degrees of the modern hydroclimate of Baja California, together with a concurrent increase in seasonably induced upwelling,[2] would appear to be sufficient to support a gradual, attenuated distribution of the thermally anomalous southern and northern species within, respectively, increasing or decreasing latitudinal gradients.[3] Unfortunately, the composition of the modern and Pleistocene faunas of critical areas of Baja California must be better known before such a distributional

[2] The occurrence of regional upwelling during interglacial phases of the Sangamon is supported by oxygen-isotope composition of *Mytilus* shells from an open-coast site on the Nestor Terrace. (Killingley and Berger, 1979).

[3] Indirect paleontological evidence supports regional episodes of hydoclimatic latitudinal shifts of this magnitude during the Pleistocene. For example, a comparison of the U-series calibrated isochron with kinetic model isochrons suggests that

model can be realistically evaluated. Additionally, absolute dates of the regional terrace sediments are needed to provide a more precise geochronological context. The only radiometric dates available for the Magdalenan provincial faunas are 116,500 ± 6,000 years for the Magdalena Terrace in Magdalena Bay (Omura, Emerson, and Ku, 1979). These values suggest this terrace is correlative with the Nester Terrace in the San Diego area and other regional terraces which apparently were formed by a high stand of the sea about 120,000 - 125,000 years ago (Ku and Kern, 1974) during a warm water stage of the Sangamon (isotopic stage 5e of Shackleton and Opdyke, 1973). The assemblages from Turtle Bay in which the warm-water indicators occur (localities B-3024 and B-3025) are probably referable to this early stage of the Sangamon. More precise dating of these assemblages and reliable correlation of the assemblages which apparently lack warm-water elements (localities B-3027, B-3007, B-3050, and B-3048) must await absolute dating of the fossils.

Register of Localities

Pleistocene, Turtle Bay area,
Baja California Sur, Mexico
California Academy of Sciences

C. A. S. loc. 34312. Between south end of Turtle Bay and the ocean. Fossil exposure about .4 kilometers from the shore line and the upper part of exposure about 15 meters above the high tide line. Shells mostly picked from a soft clay matrix, some picked up lower down in the slope. Collected by E. P. Chace, July 16, 1954. [S. D. S. N. H. loc. 0624 and U. C. M. P. loc. B-3024].

San Diego Natural History Museum

S. D. N. H. M. loc. 0624 . Southwest corner of Turtle Bay, at south end of hills on the peninsula between the bay and the Pacific Ocean. Top of exposure at an elevation of about 15 meters. Collected by E. P. Chace, July 16, 1954. [= U. C. M. P. loc. B-3024 and C. A. S. loc. 34312].

University of California Museum of Paleontology; E. C. Allison, collector

U. C. M. P. loc. B-3027. Terrace immediately behind long sandy beach along southwest portion of peninsula northwest of Turtle Bay. Elevation 4.5 to 6 meters. June 27, 1956.

U. C. M. P. loc. B-3007. Terrace deposit at about 12 meters elevation N. 30°E. of peak on south side of entrance to Turtle Bay. Jume 18, 1956.

U. C. M. P. loc. B-3050. Terrace along the northeast side of Turtle Bay. Elevation 4.5 to 6 meters. July 3, 1956.

U. C. M. P. loc. B-3024. Terrace, traceable for several hundred yards, at an elevation of 24 to 27 meters, southwest portion of Turtle Bay in back and south of small fishing camp. June 26, 1956.

U. C. M. P. loc. B-3025. Terrace at an elevation of 6 to 9 meters southwest of B-3024, and possibly equivalent to B-3024, as the terrace appears to be tilted in that direction. June 26, 1956.

U. C. M. P. loc. B-3048. Terrace at an elevation of approximately 6 meters that extends along the open coast adjacent to a long sand-gravel beach, about 9.7 kilometers southeast of Turtle Bay. July 2, 1956.

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greater air and/or ground paleotemperature reductions have occurred in coastal southern California (-4°C. for the Nestor Terrace) than in southern Baja California (-1° to -2°C. for the Magdalena Terrace) during glacial phases of the past 120,000 years (Wehmiller and Emerson, 1980).

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FRESHWATER BIVALVES OF TYGART CREEK, NORTHEASTERN KENTUCKY

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ABSTRACT

A survey of the freshwater bivalves of a small northeastern Kentucky stream revealed twenty one species of unionacean and three species of sphaeriacean clams, all reported for the first time from this area.

Several investigators have studied Kentucky bivalve mollusks. Isom reported on the clams of the Tennessee River (1969) and the Green River (1974), both of which are located in western Kentucky. Stansbery also collected in the Green River (1965) and did additional work on the Cumberland River (1969) which is located in southcentral Kentucky. Blankenship and Crocker (1972) surveyed the Rockcastle River in southeastern Kentucky and Branson and Batch (1971) collected throughout much of the state with most of their efforts concentrated in eastern Kentucky. Much of this work was concerned with land and aquatic snails, and the only bivalves reported were sphaeriacean clams. Williams (1969) comprehensive survey of the lower Ohio River basin contributed significantly to the knowledge of the molluscan fauna of Kentucky's largest major waterway.

Little work has been done in smaller streams of this area and I find no mention in the literature of any work carried out in the northeastern sector of Kentucky. The intent of this paper is to report on the occurrence and specific location of 21 species of unionacean clams and 3 species of sphaeriacean clams in a small Ohio River Tributary near the Kentucky-Ohio-West Virginia state lines.

Collecting area

The Tygart Creek basin is located in Carter and Greenup Counties in northeastern Kentucky. The direction of flow is southwest to northeast beginning in Carter County and terminating at its confluence with the Ohio River near South Shores, Greenup County, Kentucky. The stream falls 187 m in its 143 km length for an average fall of 1.3 m per km (USACE, 1977). The head-

TABLE 1. *A checklist of Mussels of Tygart Creek. Numbers in parentheses represent total number of specimens collected.*

Species collected	Station No. 1	2	3	4	5
Unionacean Clams					
Corbicula manilensis (6)		x	x	x	
Quadrula p. pustulosa (2)			x		
Amblema p. plicata (25)	x	x	x	x	
Epioblasma triquetra (13)			x		
Tritogonia verrucosa (10)			x		
Potamilus alatus (2)			x		
Elliptio dilatatus (11)		x	x	x	
Obovaria subrotunda (5)			x		
Lampsilia radiata luteola (69)		x	x	x	
Strophitus u. undulatus (17)			x	x	
Leptodea fragilis (5)			x		
Lampsilis ventricosa (19)		x	x	x	
Cyprogenia irrorata (1)			x		
Lasmigona costata (7)			x	x	
Ptychobranchus fasciolare (44)		x	x	x	
Anodonta g. grandis (2)			x	x	
Villosa iris (2)			x		
Fusconia (22)		x	x	x	
Lasmigona compressa (1)		x			
Sphaeriacean Clams					
Sphaerium simile (1)					x
Sphaerium striatinum (6)					x
Musculium transversum (15)					x

water area of Tygart Creek is characterized by narrow valleys with steep wooded hillsides. Only near the mouth is there a flood-plain of any appreciable size. The stream proper consists of a series of riffles and pools with a maximum depth along its course of just under 2 m at summer pool.

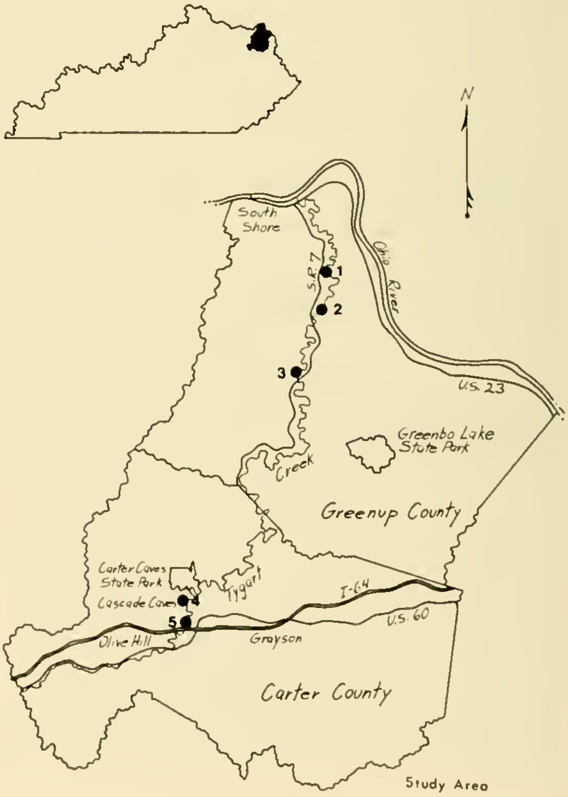
Tygart Creek is one of rather high water quality with pollution of the area being limited to that which results from local agricultural practices and to a minimal degree from input by residential human waste. There are no city sewer or industrial waste disposal systems that empty directly into the creek.

METHODS

During the period of 27 June-21 October 1977 mussels were collected in Tygart Creek. The bivalves were hand picked from the water and along the bank as dead shells. In one instance a raccoon midden provided a good cross section collection of the mussel fauna in that area. In this report no distinction is made between specimens collected as live animals or dead shells. All dead shells showed little erosion and appeared to have been recently vacated. Many sites were visited during the collecting phase but only five localities were productive. Scientific names are in accordance with Dr. David H. Stansbery of the Ohio State University Museum of Zoology where voucher specimens have been placed.

Collecting stations

Station (1) Located along St. Rt. 7, 200 m north of a covered bridge which connects Co. Rd. 1215 with St. Rt. 7., Greenup Co. A 100 m long shallow riffle with a rather swift current flowing over large rocky rubble characterize this site. The stream width is approx. 20 m.



Station (2) Located along Co. Rd. 1215, 1.12 km S. E. of a covered bridge which connects Co. Rd. 1215 with St. Rt. 7, Greenup Co. A 50 m long slow moving pool followed by a short swiftly flowing riffle and associated gravel bar characterize this site. The bottom of the pool is covered by a 15 cm layer of mud with a dense algal mat. The stream width is approx. 10 m.

Station (3) Tygart Creek northwest of the intersection of St. Rt. 7 and Co. Rd. 2070 (locally known as White Oak Road), Greenup Co. A long shallow riffle with a shaley rubble substrate is characteristic of this site. The stream width is approx. 10 m.

Station (4) A small unnamed tributary of Tygart Creek that originates in Cascade Cave. The collection site is located 300 m northeast of the Cascade Caves Park Information Center off Co. Rd. 209. (Carter Co.) This site is located in a swiftly flowing steep gradient brook with alternating riffles and pools. The substrate varies from sand bars to large boulders. The greatest stream width is 5 m.

Station (5) Tygart Creek under I-64 overpass, 0.8 km west of U. S. 60 and I-64 interchange. (Carter Co.) The stream here is relatively small and composed mostly of shallow riffles with an occasional deeper pool usually of less than 1 m depth. The substrate incorporates alternately sand bars and fine pebbles.

DISCUSSION

A total of 21 species of clams were found to be resident to this small stream. This relatively large number of species for such a small stream indicates that the water quality and habitat are conducive to habitation by a wide diversity of bivalves. All species reported herein have been previously reported from Kentucky in one or more of the papers in the introduction. None of the clams appears on Stansbery's list of rare and endangered species (1971).

From the wide diversity of types and sizes of the specimens collected it seems that the population is healthy, stable and replenishing itself while suffering little if any as a result of the progress of man.

ACKNOWLEDGMENTS

I wish to thank the following for their help in the collecting of specimens: Dwight Chaffee, Jim Ditty, Kerry Bledsoe, Steve Lawton, Marion Mallory, and John Stephen Morris. I also wish to thank Dr. David H. Stansbery of the Ohio State University for his kind help in identifying the specimens.

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OBITUARY

Wendell Oliver Gregg
1898 - 1979

Wendell O. Gregg passed away on 25 November, 1979, after months of illness and disability as a result of a series of strokes. He had been in the Huntington Park Convalescent Center since May, 1978. Born 27 April, 1898, in Pomona, Michigan, he obtained his B.A. at Andrews University, Michigan, in 1918 and then went to California where he obtained an M.D. degree at Loma Linda University in 1922.

Doc Gregg practiced medicine as a vocation, but his heart was in malacology. He was an avid and productive researcher and collector of West American land snails, particularly those of California, Nevada, and Arizona. In later years, he also became interested in the freshwater hydrobiids of southern California and Nevada.

He described several new species of *Oreohelix*, *Sonorella*, *Helminthoglypta*, *Ashmunella*, and, together with Dwight Taylor, the hydrobiid genus *Fontelicella*. He was a meticulous anatomist, and he perfected a method of making small stained whole mounts of reproductive anatomies which is used to this day by many of our professional terrestrial malacologists. He has had several species of snails named after him, notably *Helminthoglypta greggi* Willett, *Sonorella greggi* W. B. Miller, and the Baja California genus *Greggelix* W. B. Miller. In August 1973, Doc's landlady, Mrs. Greene, died, and he was forced to move to a smaller house that he owned in Huntington Park. This move was a traumatic experience and a tremendous psychological shock from which he never recovered. In late 1973, he donated his collection of shells to the Los Angeles County Museum of Natural History, and in January 1974, he donated his collection of whole mounts and his many lots of undescribed land snails to me.

During his last years in Huntington Park, Doc was tenderly cared for by Catherine Mays, an old friend, who lived with him and looked after him. She was at his bedside every day of his year-and-a-half stay at the Convalescent Center.

Doc Gregg introduced me to desert collecting in 1956 and was my constant companion and mentor for eight years of camping and collecting trips. He painstakingly taught me his techniques for dissecting, staining, and mounting anatomies. He provided the inspiration and confidence which led me to a second career as a terrestrial malacologist and professor of biology.

In the peace and solitude of the desert arroyos, when twilight falls and the evening breeze rustles the creosote bush, I will remember Doc and the countless campfires we shared together.

Walter B. Miller
Professor of Biology
and Curator of Invertebrates
University of Arizona, Tucson, Arizona

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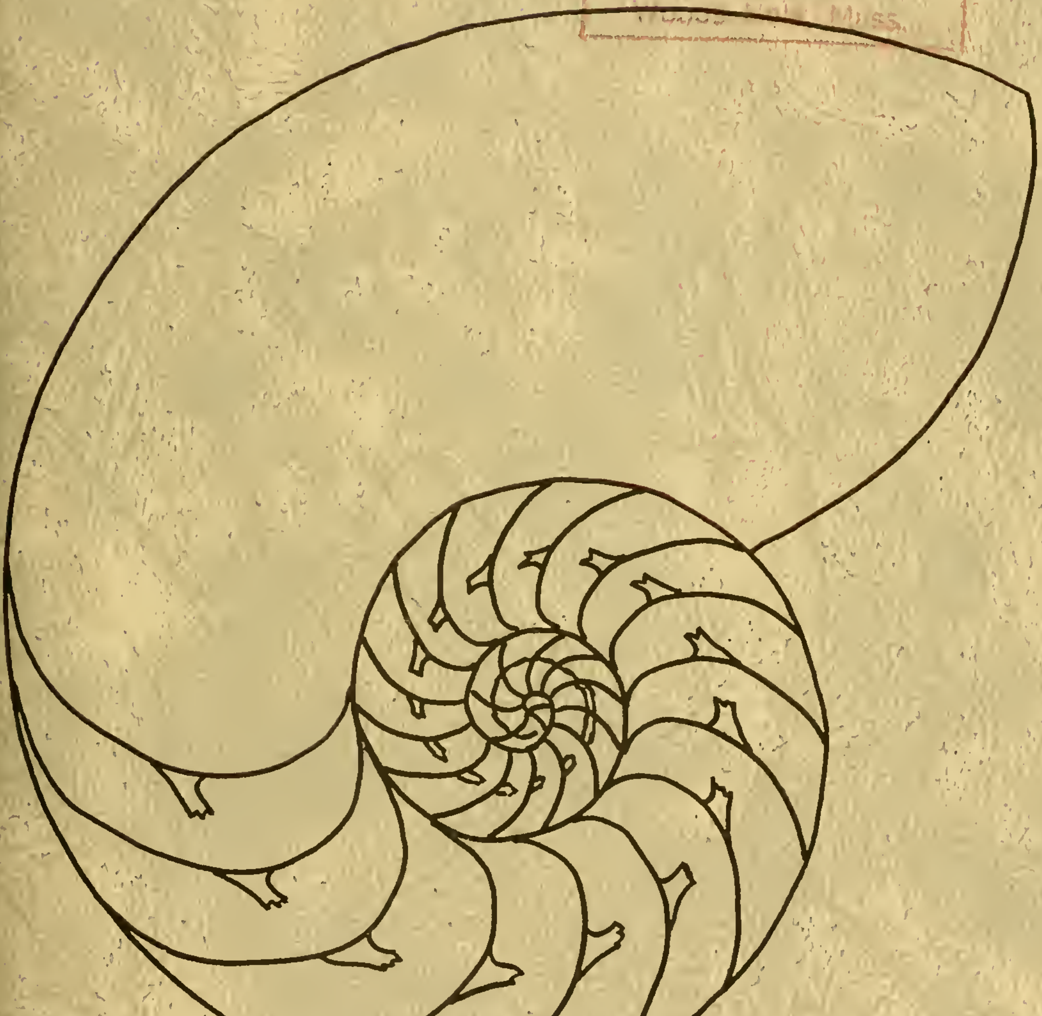

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NOTES ON THE PREHISTORIC AND PRESENT STATUS OF THE NAIAD FAUNA OF THE MIDDLE CUMBERLAND RIVER, SMITH COUNTY, TENNESSEE

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ABSTRACT

Examination of cull and stock piles of naiads taken by commercial musselers working the Cumberland River, Smith County, Tennessee, during the years 1977-1979 has provided significant data on the abundance, growth, reproduction, and survival status of 40 species still inhabiting this section of the river. Brail samples taken 6 September 1979 supplements these data with specific information on species diversity and population densities in the three largest mussel beds fished commercially. Populations of at least 14 extant species are low and five of these, Plethobasus cooperianus, Epioblasma sulcata, E. brevidens, Cyprogenia irrorata, *and* Dromus dromas *are comprised of a few relic individuals. Samples of archaeological shell collected from two prehistoric rock shelter deposits near two of the existing mussel beds contained valves of 42 species, of which seven are now extinct and six no longer inhabit the middle Cumberland River.*

The entire course of the Cumberland River flowing through north-central Tennessee has been altered as a result of the construction of several electric power dams by the United States Corps of Engineers. Certain stretches of the river between Dale Hollow Reservoir on the east, Old Hickory Lake above Nashville, and Barkley Lake on the west near its confluence with the Ohio River still maintain some characteristics of an unimpounded stream. However, increased depth, fluctuating water levels, and elimination of most of the former shoals and riffles have greatly affected the original biota, especially the mollusks. Prior to impoundment, the Cumberland River contained an abundant and diversified naiad fauna, but with the establishment of existing conditions the number of mussel species inhabiting the river was reduced and, for the most part, restricted to a few major beds. While some species such as *Megalonaias gigantea, Pleurobema cordatum, Quadrula pustulosa,* and *Plagiola lineolata,* have adjusted to impoundment and are maintaining viable populations, others exist as relic individuals or in very limited numbers. The study by Wilson and Clark (1914) provides the most comprehensive record of the naiad fauna of the entire Cumberland River and its tributaries prior to impoundment. Neel and Allen (1964) reported the mussel fauna of the upper Cumberland River (in Kentucky) before impoundment, while Stansbery (1969) reported on the changes that took place in the naiad fauna of this section of the river after impoundment.

Our interest in the naiad fauna of the section of the Cumberland River that flows through Smith County was stimulated by searching for study specimens through cull and stock piles of freshly caught mussels taken by commercial shellers operating out of Rome, Tennessee. Examination of these shell piles periodically during the summers of 1977, 1978, and 1979 revealed noteworthy information on the extant mussel populations and the species composition comprising the three major beds that were being worked consistently by commercial shellers. The fortuitous discovery in 1976 of specimens of

Epioblasma (formerly *Dysnomia*) *sulcata* in sheller's cull piles, a species that had been presumed extinct (Stansbery, 1970) or reduced to a single population in the Green River, Kentucky (Stansbery, 1971), was reported by Isom, Gooch, and Dennis (1979) and resulted in a mussel survey of the Cumberland River between CRM 284.3 and CRM 305.3 by TVA biologists (TVA, 1976). This latter unpublished in-house report provides pertinent distribution and abundance data on mussel populations in this 33.6 km stretch of the river. Our contribution (this paper) supplements this study with additional quantitative population data, records of species previously unreported in the recent literature, and an evaluation of species adjustment to present river conditions.

The mean and maximum depth, current flow and width at any given point of the Cumberland River flowing through Smith County is controlled by power generating activities of Cordell Hull Dam, located approximately 33.6 km upstream from Rome. Water levels may fluctuate as much as two meters during a 24-hour period. These almost daily extremes in the water level and the minimum depth of the main channel which has increased 3 to 4.5 m since impoundment have resulted in adverse conditions affecting population and individual growth and the reproductive potential for numerous naiad species still inhabiting the river. Heavy commercial harvesting of shell (usually April through September) in the Cumberland River in Smith County during 1975-1979 has provided an excellent opportunity to supplement recent mussel population surveys (e.g. TVA, 1976) and to evaluate the present occurrence, relative abundance, and physical condition of extant naiad species.

Naiad Species Composition

Although some commercial shellers retain only those few species that command the highest price (e.g. *M. gigantea, P. cordatum*), others keep all specimens taken with the brail, regardless of species, size, and nacre color. "Pinks" such as *Elliptio dilatatus, Elliptio crassidens*, and *Cyclonaias tuberculata* are sold separately at a minimal price, while the variety of other small species—occasionally termed "grinders"—are sold together as a separate category. Examination of cull and stock piles that represent total catches have proved especially useful in determining the presence and relative abundance of mussel species in this stretch of the Cumberland River. To supplement this resource, however, it was felt that a systematic collection/survey of the three major mussel beds would provide more exact data on relative abundance and species composition. On 6 September 1979, approximately eight hours were spent with a commercial sheller; using two 4.8 m brails, four-to-six 450 m drags were made over the beds at Rome Island (CRM 291.0), Plunkett Creek (CRM 293.0), and Bartletts Bar (CRM 296.8). A total of 1,100 specimens, representing 27 species, was taken; a list of the species collected and the numbers of each and their percentage for each bed are presented in Table 1.

Four species, *M. gigantea, P. cordatum, Q. pustulosa*, and *P. lineolata* comprised 82 percent of the catch, while specimens of 16 species amounted to less than one percent each of the total. Differences in the occurrence and/or abundance of most species among the three beds was quite apparent. Although the bottom strata, consisting of a gravel-sand mixture, is relatively uniform at CRM 291 and 296.8, the mean depth of the main channel increases from about 4.5 m at Bartletts Bar to about 7.5 m at Rome Island. A few species such as *P. lineolata* occurred in about equal numbers in all three beds, but most exhibited considerable variation in abundance between beds, as evidenced from an admittedly limited brail sample taken during a single eight-hour period. However, these limited data suggest that Bartletts Bar, which is shallower and has a somewhat swifter current than the other two downstream beds, provides more suitable habitat conditions for a greater number of species. Such beds and/or small isolated bars appear to still serve as a refugium for many species which once occurred commonly in the shoals and riffles but that now have all but disappeared from the former Cumberland River naiad fauna. As the river current slows and siltation begins on approach to Old Hickory Reservoir, only a few typically deep water naiads, or those that have adapted to impoundment conditions, can survive.

In addition to the 27 species collected by brail on 6 September 1979, shells of 11 additional

TABLE 1. *Mussels obtained from three beds in the Cumberland River, Smith County, Tennessee. Specimens collected from a commercial sheller's boat by brail. September 6, 1979.*

	MUSSEL BED							
	Bartletts Bar CRM 296.8 River depth c. 4.5m Bed length c. 0.8km		Plunkett Creek CRM 293 River depth c. 6.1-7.6m Bed length c. 1.6km		Rome Island CRM 291 River depth c. 9.1m Bed length c. 3.2km			
Species	No. of specimens	%	No. of specimens	%	No. of specimens	%	Total No. of specimens	% of all specimens
Amblema plicata (Say, 1817).			3	.76	1	.30	4	.36
Fusconaia ebena (Lea, 1831).					2	.61	2	.18
Fusconaia subrotunda (Lea, 1831).	8	2.09					8	.72
Fusconaia undata (Barnes, 1823).					2	.61	2	.18
Quadrula metanevra (Raf., 1820).	7	1.83	2	.50	2	.61	11	.99
Quadrula pustulosa (Lea, 1831).	37	9.66	13	3.27	24	7.27	74	6.67
Tritogonia verrucosa (Raf., 1820).	3	.78	3	.76	2	.61	8	.72
Megalonaias gigantea (Barnes,1823).	104	27.15	239	60.20	133	40.30	476	42.88
Cyclonaias tuberculata (Raf., 1820).	25	6.53	2	.50	1	.30	28	2.52
Elliptio crassidens (Lamarck, 1819).	3	.78	16	4.03	13	3.94	32	2.88
Elliptio dilatatus (Raf., 1820).	4	1.04	2	.50			6	.54
Truncilla truncata (Raf., 1820).			1	.25			1	.09
Plethobasus cooperianus (Lea, 1834).	3	.78					3	.27
Plethobasus cyphyus (Raf., 1820).			1	.25			1	.09
Pleurobema cordatum (Raf., 1820).	124	32.88	60	15.11	101	30.61	285	25.68
Pleurobema coccineum (Conrad, 1836).	3	.78	5	1.26	3	.91	11	.99
Lasmigona complanata (Barnes, 1823).			4	1.01	2	.61	6	.54
Lasmigona costata (Raf., 1820).	1	.26					1	.09
Actinonaias ligamentina (Lamarck,1819).	6	1.57	3	.76	4	1.21	13	1.17
Epioblasma sulcata (Lea, 1829).	1	.26					1	.09
Lampsilis orbiculata (Hildreth, 1828).	2	.52					2	.18
Ligumia recta (Lamarck, 1819).	1	.26			1	.30	2	.18
Obliquaria reflexa (Raf., 1820).	4	1.04	5	1.26	11	3.33	20	1.80
Plagiola lineolata (Raf., 1820).	29	7.57	23	5.79	25	7.58	77	6.94
Dromus dromas (Lea, 1834).	1	.26					1	.09
Ptychobranchus fasciolaris (Raf., 1820).	14	3.66	2	.50	2	.61	18	1.62
Potamilus alatus (Say, 1817).	3	.78	13	3.27	1	.30	17	1.53
	383	99.98	397	99.98	330	100.01	1,110	99.99

species have been recovered from sheller's cull and stock piles that were obtained from Cumberland River beds in Smith County in the summers of 1977-1979. These species are as follows:

Anodonta grandis (Say, 1829). Floater
Quadrula quadrula (Raf., 1820). Maple-Leaf
Pleurobema plenum (Lea, 1840). Rough Pigtoe
Pleurobema pyramidatum (Lea, 1829).
Cyprogenia irrorata (Lea, 1829). Fan Shell
Quadrula cylindrica (Say, 1817). Rabbits-Foot
Obovaria olivaria (Raf., 1880). Hickory-Nut
Lampsilis teres teres (Raf., 1820). Yellow Sand Shell
Lampsilis teres fallaciosa (Smith, 1899). Slough Sand Shell
Lampsilis ovata (Say, 1817). Pocketbook

Epioblasma triquetra (Raf., 1820). Snuffbox
Epioblasma brevidens (Lea, 1831).

Compared with *M. gigantea* or *P. cordatum*, all 11 of these species may be arbitrarily classified as uncommon or rare (less than one percent of a sample of 1,000 specimens). Although the relative abundance of species listed in Table 1 that comprised less than two or three percent of the total implies a similar classification, there are exceptions judging from estimated numbers observed in sheller's cull and stock piles. *E. crassidens*, *C. tuberculata*, *Ptychobranchus fasciolaris*, *Actinonaias ligamentina*, and *Lampsilis orbiculata*, for example, are taken in considerable numbers by shellers during a season's operation. Nevertheless, of the approximately 40 naiad species recorded from the middle Cumberland River, Smith County, during this three year period, about half may be arbitrarily classified as uncommon to rare in occurrence.

In spite of atypical habitat conditions brought about through impoundment and the reduction in individual numbers as a result of intensive shelling operations during the last two decades, several species have been able to successfully reproduce and maintain viable populations. In addition to the primary commercial species, others, including *Lasmigona complanata*, *Tritogonia verrucosa*, *Elliptio dilatatus*, *Amblema plicata*, *Quadrula metanevra*, *Pleurobema coccineum*, and *P. fasciolaris*, appear to be reproducing, as evidenced from the taking of occasional juvenile or young individuals, to the extent of at least maintaining low but stable populations. Occasional mature or old specimens of a few species such as *Fusconaia ebena* and *Plethobasus cyphyus* are taken by the shellers; we have not seen juveniles from this section of the river, but if these and a few other uncommon to rare species are reproducing, the rate is extremely slow.

Endangered and Relic Species

Three species, *Lampsilis orbiculata*, *Dromus dromas*, and *Plethobasus cooperianus* that are listed in the *Federal Register of Endangered and Threatened Wildlife and Plants* still inhabit the middle Cumberland River. Although *L. orbiculata* is classified as endangered, probably 150-200 individuals, both males and females, have been noted in sheller's cull piles. Tennessee Valley Authority biologists (TVA, 1976) found the Pink Mucket distributed throughout the section of river they sampled in September 1976 (CRM 284.3-305.3) that includes both fast water (Bartletts Bar) and impounded habitat at Hartsville and downstream. No juvenile specimens of *L. orbiculata* were noted in our survey, but considering the abundance and distribution of this species in the river and its continual appearance in commercial catches, some reproduction may be taking place.

On the other hand, both *D. dromas* and *P. cooperianus* are rare and, judging by their estimated age (>20 years), heavy valves, and obvious maturity, the populations of these species are comprised of non-reproducing relic individuals. In addition to the one specimen taken 6 September 1979, only five individuals and two single valves of *D. dromas* were observed in sheller's cull and stock piles during the summers of 1977-1979. A right valve of *P. cooperianus* was found in a cull pile at Rome in June 1979 and three old individuals (Mean: shell gram weight, 158.4; shell mm length, 79.5; height, 68.8; width, 43.5) were taken at Bartletts Bar 6 September 1979. Wilson and Clark (1914:28) reported the Cumberland Pigtoe, *P. cooperianus*, and the Mucket, *A. ligamentina*, second only in abundance to the Pigtoe, *P. cordatum*, in a large sheller's cull pile near Celina, Tennessee on the lower Cumberland River. *P. cooperianus* has not been previously reported from any area of the Cumberland River since its impoundment; Neel and Allen (1964:436) commented that it was "Also rare in the upper Cumberland in the late 1940's . . ." and Stansbery (1969) failed to encounter *P. cooperianus* in his 1961 survey of the river at Cumberland Falls, Kentucky.

The fact that the Cumberland and Tennessee River systems form of the Cats Claw, *Epioblasma (=Dysomia) sulcata sulcata* (Lea, 1829), was considered probably extinct (Stansbery, 1970:19) precluded its inclusion in the *Federal Register* of endangered species. It is, however, endangered and, as Isom, Gooch, and Dennis (1979:84) pointed out, ". . . is believed to be confined to this portion [c. CRM 291-297] of the Cumberland River in Tennessee." Their report (Isom, Gooch, and Dennis, 1979) provided a record of the significant

TABLE 2. *Shell measurements of* Epioblasma sulcata sulcata *from the Cumberland River, Smith County, Tennessee.*

Sex	No. of Specimens	Observed Range (Mean)			
		Weight gm	Length mm	Height mm	Width mm
Female	5	31.6-47.2 (40.2)	41.9-53.0 (46.6)	34.5-40.5 (38.0)	30.0-36.4 (32.0)
Male	51	48.2-107.4 (76.3)	52.0-67.3 (60.6)	40.3-50.4 (44.7)	31.3-42.4 (37.4)

discovery of this species as a member of the present middle Cumberland River naiad fauna, but specific data for recovered specimens were lacking. During our 1977-1979 surveys, a total of 56 complete specimens (paired valves) and eight right and five left valves of *E. s. sulcata* were obtained as discards from commercial shellers; these individuals were taken by brail within the CRM 291-297 stretch of the river. Of special note is the fact that, of the 80 individuals (including unpaired valves of 13 males, 1 female) represented in the sample, 74 (or 92 percent) were males. Observed range and mean measurements of 5 females and 51 males presented in Table 2 provides heretofore unavailable data on the big river form *E. s. sulcata.* Although the annual rest lines on all specimens were crowded and often indistinct, no individual appeared to be less than 20 years old. The degree of shell erosion varied from slight on a few individuals to extensive in most (in many specimens the entire umbo and dorsal surfaces were eroded away: see Figure 1). Although this naiad was reported to have been ". . . pretty well distributed along a considerable stretch of the river . . ." and was ". . . common enough to be pretty well known to the clammers . . ." (Wilson and Clark, 1914:46), the remaining numbers of *E. s. sulcata* almost certainly represent non-reproducing relics.

Wilson and Clark (1914:53) commented that the Fan Shell, *Cyprogenia irrorata,* was ". . . of rather infrequent occurrence in the Cumberland" and that it ". . . seems to inhabit rather deep water." We recovered seven complete specimens and one single valve during our survey. Measurements of these specimens, compared with those of three mature individuals from the Clinch River, Hancock County, Tennessee are presented in Table 3. Although downstream (big river) specimens normally exhibit a greater degree of shell inflation, these seven individuals represent extremes in shell inflation and weight (see Figure 1, Table 3). The mean weight of the Cumberland River forms is over twice that of the Clinch River specimens and one-fourth greater in width. *C. irrorata* is presently a rare species in the Cumberland River and the population is comprised of old relic individuals.

Two other species of *Epioblasma, E. triquetra* and *E. brevidens,* still inhabit sections of the middle Cumberland River and are as rare as *E. sulcata,* or perhaps even of greater rarity, judging by the few individuals recovered. Shellers report taking both "once in a while"; we obtained only eight specimens of the former species and one of the latter during searches of cull and stock piles in 1977-1979. Although Wilson and Clark (1914:45) stated that the Snuffbox occurred only in the upper part of the river, apparently small populations of *E. triquetra* once inhabited suitable shoal areas downstream as far as Smith County. Valves of the eight Cumberland River specimens of *E. triquetra* were thick and considerably inflated, but none, like the specimens of *D. dromas,* exceeded in size large individuals collected in unimpounded stretches of the upper Clinch or Powell

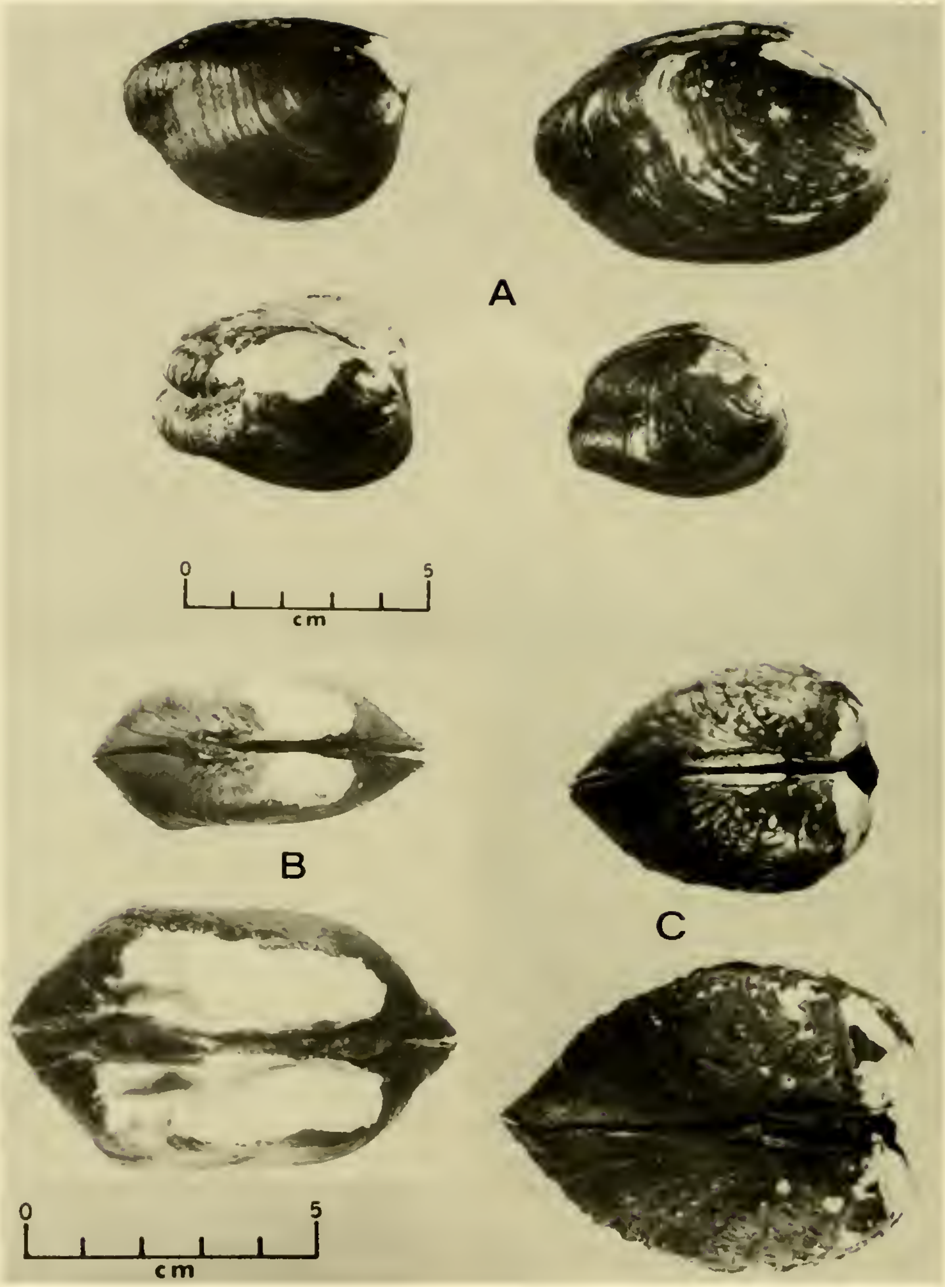

FIG. 1. *Examples of* Epioblasma sulcata sulcata **A,** *from the Cumberland River, TN (males, top; females, bottom). Comparison between adult female* Epioblasma brevidens **B,** *from the Powell (top) and Cumberland (bottom) rivers, and between adult specimens of* Cyprogenia irrorata **C,** *from the Tennessee (top) and Cumberland (bottom) rivers, TN.*

rivers, Hancock County. In contrast, however, the one female specimen of *E. brevidens* that we obtained exhibits a tremendous degree of shell inflation, thickness, and weight (see Table 3, Figure 1). Obviously an extremely old individual with considerable shell erosion, the weight of this specimen exceeded the Mean weight of four adult females from the Powell river by nearly four (110.0 grams vs. Mean of 29.6) and a width of slightly less than twice (40.0 mm vs. Mean of

TABLE 3. *Comparative shell measurements of* Cyprogenia irrorata *and* Epioblasma brevidens *from the Cumberland River, Smith County with a series of each species from the Clinch and Powell rivers, Hancock County, Tennessee.*

1. Cyprogenia irrorata		Observed Range (Mean)			
River	No. of Specimens	Weight gm	Length mm	Height mm	Width mm
Cumberland	7	78.6-163.1 (110.5)	53.6-66.7 (59.9)	47.5-58.2 (51.9)	36.5-46.9 (41.1)
Clinch	3	43.7-51.7 (48.9)	47.8-52.5 (50.0)	45.3-46.2 (45.7)	30.5-32.0 (31.4)
2. Epioblasma brevidens					
Cumberland	1	110.9	72.0	45.8	40.0
Powell	4	27.0-33.0 (29.6)	54.0-57.3 (55.2)	35.3-38.0 (36.5)	22.3-26.6 (24.0)

24.0). As is the case with individuals of numerous species comprising the naiad fauna of this stretch of the river, these two typically small river or shoal forms are surviving as old adults but are no longer able to propagate as a result of habitat changes brought about by impoundment. Elimination of the fish species that serves as host to the glochidia is another possibility.

During their 1976 mussel survey of the middle Cumberland River, TVA biologists reported (TVA, 1976: Appendix I, Table IX) finding "relics" of *Cumberlandia monodonta* (Say, 1829) and a specimen or specimens of *Obovaria retusa* (Lamarck, 1819) at a cook out area used by musselers. However, no location of the finds or number of specimens observed were given. Although *C. monodonta* was apparently of only "occasional" occurrence in the Cumberland River (Wilson and Clark, 1914:52), remaining populations must be comprised of extremely few relic individuals. TVA biologists (TVA, 1976:8) also mention finding two specimens of *Quadrula sparsa* (Lea, 1841) at a cook out station at CRM 270, and commented that these individuals of this endangered species were probably taken near this point. The presence of *Q. sparsa*, a typically small stream or shallow riffle species, in an impounded section of the Cumberland River (Old Hickory Reservoir) is unusual since neither Wilson and Clark (1914) nor Neel and Allen (1964) mention its occurrence anywhere in the river. In actuality, these specimens are probably *Q. metanevra* lacking pustules.

TVA biologists recorded a single specimen of *Obovaria olivaria* taken at c. CRM 277.0 below Hartsville Island (TVA, 1976: Table XII), but none from any of the other river sections surveyed. We obtained a total of 19 mature individuals (13 complete specimens, 2 left and 4 right valves) that had been taken between CRM 291 and 297. Although reported from the Clarksville area by Wilson and Clark (1914:52), its former status upstream is unknown. Presently it appears to be an uncommon to rare species in the middle Cumberland River.

The population status of several other middle

Cumberland River naiads including *Lasmigona costata*, *Truncilla truncata*, *Lampsilis teres*, and *Plethobasus cyphyus* is questionable, but all appear to be uncommon to rare in occurrence. Commercial shellers report taking *L. costata*, a species more typical of small streams, and *L. teres* only occasionally; we recovered less than five specimens of each species during our survey. Specimens of *T. truncata* are rarely taken and although *P. cyphyus* and *Lampsilis ovata* appear not infrequently in cull and stock piles, existing populations must be low. The fact that many of the species typical of small-to-medium size rivers and/or a riffle habitat have been able to survive in the middle Cumberland River under the atypical conditions brought about by impoundment is remarkable.

Archaelogical Naiad Samples

Published data dealing with the prehistoric distribution and species composition of mussels of the middle Cumberland River are lacking. For this reason, and as a useful comparison between prehistoric and modern naiad faunas, rock shelters containing primarily Woodland Period (c. 1000 BC-AD 1000) middens near the surface, located adjacent to beds currently being worked by commercial shellers, were sampled (Table 4). The Plunkett Creek shelter (40SM74; c. CRM 293) is immediately west of the confluence of Plunkett Creek and the Cumberland River; Rome Island shelter (40SM75; c. CRM 291) is situated against the Cumberland River bluff opposite the NW end of Rome Island. The surface deposits at both sites had been disturbed by relic collectors and the samples of valves identified and recorded in Table 4 were obtained from the disturbed areas and back dirt piles. Although the quantity of specimens obtained was not great (c. 1550 valves), the species represented in these archaeological samples provide noteworthy records of prehistoric distribution, relative abundance, and species composition of mussels formerly inhabiting this stretch of the Cumberland River.

Seven species of the genus *Epioblasma (arcaeformis, haysiana, flexuosa, lewisi, propinqua, torulosa, stewardsoni)* that once occurred in this section of the river are now extinct, two *(florentina, capsaeformis)* no longer inhabit the impounded sections, and two species *(brevidens, sulcata)* survive as relic populations of old, apparently non-reproducing individuals. The status of *E. triquetra* is uncertain; on rare occasion specimens, most of which are thick shelled and greatly inflated compared with their length, are taken with a brail. If the species is still propagating, the rate must be slow as evidenced by the extremely few individuals encountered. Judging from these two archaeological samples, at least 11 species of *Epioblasma* inhabited the middle Cumberland River prehistorically; populations of *propinqua*, *arcaeformis*, and *stewardsoni* appear to have been the most numerous of this complex. As Stansbery (1971:8) has pointed out, "All species in this genus [*Epioblasma*] are characteristic riffle or shoal species inhabiting those parts of streams which are shallow with sandy-gravel substrate and rapid currents." This habitat type in the Cumberland River was largely eliminated with impoundment and with it most populations of naiad species that had adapted to it.

Similarities in shell morphology among several species of *Epioblasma*, especially in the case of males, present identification problems with archaeological specimens that are especially difficult if not impossible to resolve. This has proved to be especially true with the *propinqua/torulosa/sulcata* complex and the *flexuosa/lewisi/stewardsoni* complex. Disintegration of the periostracum, loss of nacre color, and the often fragmentary condition of valves compound the problem. In addition, resolving taxonomic status, i.e., does a particular specimen represent a distinct species, an ecotype, or a special habitat or clinal variation, is important in arriving at accurate interpretations. Ortmann (1925:364), for example, comments that "*D. propinqua* is merely a *torulosa* with the tubercles very poorly or not all developed, and the two forms actually intergrade in this respect." Other malacologists (e.g. Stansbery, 1971; Johnson, 1978) consider these "forms" as valid species. In contrast, Johnson (1978) synomyzes *Plagiola (=Epioblasma) lewisi* with *flexuosa*, regarding *lewisi* as merely an ecophenotypic variant. For this particular study, we have chosen to follow Stansbery's view that

the 12 species of *Epioblasma* discussed in the preceding paragraph are valid.

There appears to be some question as to the historic occurrence of several species of *Epioblasma* in the Cumberland River from the beginnings of systematic scientific collecting in the river system to the period of dam construction. To illustrate, neither Wilson and Clark

TABLE 4. *Naiad samples from two prehistoric rock shelter deposits along the Cumberland River, Smith County, Tennessee.*

Species	Plunkett Creek Shelter 40SM74		Rome Island Shelter 40SM75	
	No. of valves	% of total	No. of valves	% of total
Amblema plicata (Say, 1817). Three-Ridge	2	.28	11	1.33
Fusconaia subrotunda (Lea, 1831). Long Solid	20	2.80	12	1.45
Fusconaia undata (Barnes, 1823). Pig-Toe			1	.12
Quadrula cylindrica (Say, 1817). Rabbits-Foot	5	.70	3	.36
Quadrula metanevra (Raf., 1820). Monkey-Face	3	.42	9	1.09
Quadrula pustulosa (Lea, 1831). Warty-Back	7	.98	10	1.21
Cyclonaias tuberculata (Raf., 1820). Purple Warty-Back	25	3.50	26	3.14
Elliptio crassidens (Lamarck, 1819). Elephant Ear	21	2.94	24	2.90
Elliptio dilatatus (Raf., 1820). Spike	155	21.68	175	21.16
Lexingtonia dolabelloides (Lea, 1840). Slab-Sided Mussel	4	.56	19	2.30
Plethobasus cooperianus (Lea, 1834). Cumberland Pig-Toe	3	.42	7	.85
Plethobasus cicatricosus (Say, 1829). White Warty-Back	2	.28	1	.12
Plethobasus cyphyus (Raf., 1820). Sheepnose			2	.24
Pleurobema clava (Lamarck, 1819).	39	5.45	35	4.23
Pleurobema cordatum (Raf., 1820). Ohio River Pig-Toe	3	.42	2	.24
Pleurobema plenum (Lea, 1840). Rough Pig-Toe	19	2.66	26	3.14
Pleurobema pyramidatum (Lea, 1834).	24	3.36	22	2.66
Pluerobema coccineum (Conrad, 1836).	3	.42	7	.85
Pleurobema spp.	16	2.24	66	7.98
Lasmigona costata (Raf., 1820). Fluted Shell	1	.14		
Actinonaias ligamentina (Lamarck, 1819). Mucket	82	11.47	130	15.72
Epioblasma arcaeformis (Lea, 1831). Sugar Spoon	11	1.54	27	3.26
Epioblasma brevidens (Lea, 1831).	4	.56	4	.48
Epioblasma florentina (Lea, 1857). Yellow-Blossom Mussel	2	.28	1	.12
Epioblasma capsaeformis (Lea, 1834). Oyster Shell	2	.28	2	.24
Epioblasma haysiana (Lea, 1834). Acorn	1	.14	2	.24
Epioblasma stewardsoni (Lea, 1852).	8	1.12	9	1.09
Epioblasma sulcata (Lea, 1829). Cats Claw/E. torulosa (Raf., 1820). Green-Blossom/E. propinqua (Lea, 1857)	53	7.41	21	2.54
Epioblasma flexuosa (Raf., 1820).			1	.12
Epioblasma cf. lewisi (Walker, 1910). Leaf Shell			2	.24
Lampsilis fasciola (Raf., 1820).	6	.84	1	.12
Lampsilis orbiculata (Hildreth, 1828). Pink Mucket			1	.12
Lampsilis ovata (Say, 1817). Pocketbook	12	1.68	9	1.09
Ligumia recta (Lamarck, 1819). Black Sand Shell	3	.42	1	.12
Obovaria retusa (Lamarck, 1819). Ring Pink	3	.42	7	.85
Obovaria subrotunda (Raf., 1820).	3	.42	5	.60
Potamilus alatus (Say, 1817). Purple Heel-Splitter	1	.14	1	.12
Villosa iris (Lea, 1829). Rainbow Shell	1	.14		
Villosa taeniata (Lea, 1865).	6	.84	12	1.45
Cyprogenia irrorata (Lea, 1829). Fan Shell	5	.70	5	.60
Obliquaria reflexa (Raf., 1820) Three-Horned Warty-Back	1	.14		
Dromus dromas (Lea, 1834). Camel Shell	147	20.56	111	13.42
Ptychobranchus fasciolaris (Raf., 1820). Kidney Shell	12	1.68	17	2.06
	715	100.03	827	99.97

(1914) nor Neel and Allen (1964) recorded *E. propinqua, E. torulosa, E. stewardsoni, E. flexuosa,* and *E. lewisi* from any stretch of the Cumberland River flowing through Tennessee. Neel and Allen (1964:450) did collect one specimen of *E. lewisi* at each of two locations in the upper Cumberland River in Kentucky; these records have been plotted on the distribution map by Johnson (1978:300, plate 5) as *Plagiola (=Epioblasma) flexuosa.* Ortmann (1926:182) provides an interesting comment as to the possible former occurrence of *E. torulosa* in the Cumberland River: "I have not been able to find any *published* record for this species from the Cumberland . . . yet Walker has informed me that he has specimens of *torulosa* from the Cumberland . . . probably were collected at Nashville by Dr. Lindsey in 1877. This seems to establish the presence of *torulosa* in the Cumberland River, although the information is subject to doubt, and it is remarkable that this species never again has been found in the Cumberland."

The two archaeological samples that we obtained contained several examples of distinct *E. stewardsoni,* one valve of a male *E. flexuosa,* and two valves of females that closely approach *E. lewisi* (see Table 4, Figure 2). The problems of distinguishing subfossil valves of *propinqua/sulcata/torulosa* have been discussed; although many of the archaeological specimens compare closely with one or the other of these species, their condition and a lack of recent comparative material from the middle Cumberland River makes species determinations less than certain. The archaeological samples do, however, establish without question the former occurrence of prehistoric populations of *E. propinqua* and/or *E. torulosa,* as well as *E. stewardsoni* and *E. flexuosa,* in the middle Cumberland River. In 1978, Klippel recovered a small sample of naiads from two shell middens along the Cumberland River at Nashville (Davidson County) that included, in addition to 38 valves morphologically closest to *propinqua* and/or *sulcata,* two specimens of *E. torulosa* (Figure 2). These shells resemble the species or form *cincinnatiensis,* recently synomyzed with *torulosa* by Johnson (1978:262). Emanuel Breitburg, previously with the Tennessee Division of Archaeology, Department of Conservation, Nashville, identified a large sample of naiads from an archaeological site (Late Archaic) in Jackson County (40JK25) that was excavated in 1976 by Ms. Patricia Cridlebaugh, Department of Anthropology, University of Tennessee, Knoxville. In addition to c. 600 valves of *E. propinqua/E. sulcata,* he identified (unpublished list on file, Division of Archaeology) 10 specimens as *E. t. cincinnatiensis.* From these archaeological records, therefore, it is apparent that five previously unreported (or unverified) species of *Epioblasma* from the middle Cumberland River in Tennessee were present in prehistoric times. Until additional and larger archaeological samples are collected and studied, however, more exact relationships among the species cannot be realized.

At least six other species represented in the archaeological samples that are now extirpated from the middle and lower Cumberland River, directly or indirectly as a result of impoundment, also occur typically in shallow, fast-flowing riffles and shoals. These species include *Lexingtonia dolabelloides, Pleurobema clava, Lampsilis fasciola, Obovaria subrotunda, Villosa iris,* and *V. taeniata.* The former occurrence of *P. clava* in this stretch of the river is noteworthy; valves of this species comprised slightly more than five percent of the total shells collected at the Plunkett Creek shelter and four percent at the Rome Island shelter which suggest the species had been well established at these locales. Because of the lack of well-documented specimens, Ortmann (1925:340) concluded that ". . . the presence of *clava* in the Cumberland remains doubtful." Wilson and Clark (1914:57) stated that it was "Generally rare, and not found at all below Burnside." The other five species, although now extirpated from the main Cumberland River, still occur as local populations in unimpounded sections of Tennessee rivers such as the Duck and the upper Clinch and Powell.

It should be pointed out that some specimens recorded in Table 4 as *A. ligamentina* may be *L. orbiculata.* Except for the greatly inflated posterior section of shells of female *L. orbiculata,* valves of these two species from an archaeological context are impossible to differentiate.

The fact that populations of several other in-

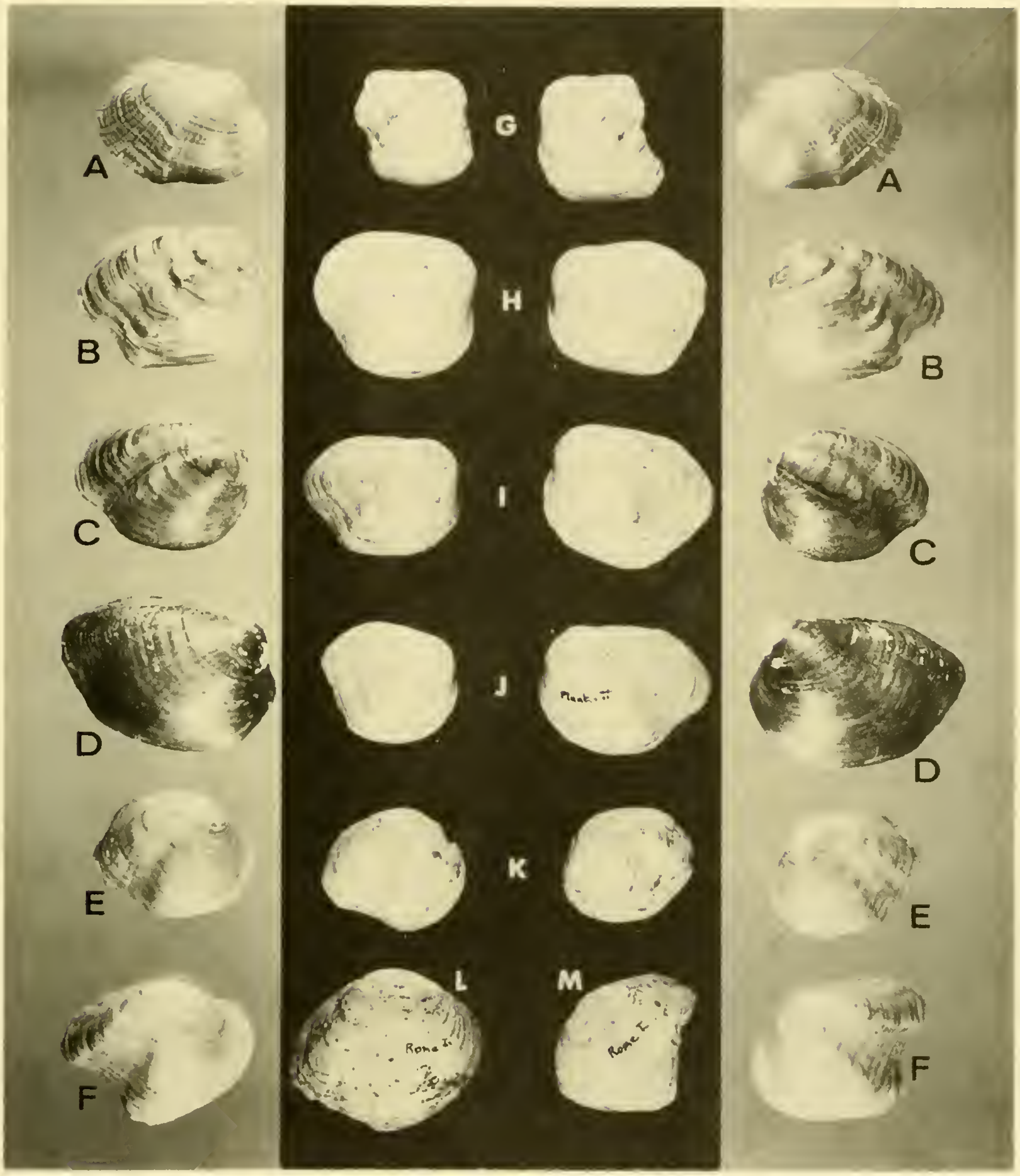

FIG. 2. *Examples of naiads from Cumberland River archaeological shelters* (**G-J**, Epioblasma torulosa propinqua/sulcata *complex;* **K**, E. stewardsoni; **L**, E. flexuosa; **M**, E. *cf.* lewisi) *compared with fresh specimens of* E. torulosa gubernaculum **A**, E. t. torulosa **B**, E. propinqua **C**, E. sulcata **D**, E. stewardsoni **E**, E. flexuosa, **F**

habitants of the middle Cumberland River, species such as *P. cooperianus, O. retusa, C. irrorata,* and *D. dromas,* have been reduced to a few relic individuals has been discussed. Although Wilson and Clark (1914:60) mention *P. cooperianus* as "Not rare in the Cumberland", only 10 valves were recovered at the two archaeological sites. The same authors comment that *C.*

irrorata was of infrequent occurrence in the Cumberland, and our limited archaeological samples seem to bear out this observation, at least for this locality. On the other hand, Wilson and Clark (1914:53) noted that *Obliquaria reflexa* was "One of the most common shells of the river, and found throughout its entire length"; we obtained only one valve at the Plunkett Creek shelter. In the main river, the population status of *D. dromas* was recorded as ". . . of occasional occurrence" by Wilson and Clark (1914:53), yet valves of the Camel shell comprised 20 percent of the shell sample from the Plunkett Creek shelter and 13 percent at the Rome Island shelter. Differences in the species composition among mussel beds is not unusual and may well account for certain apparent discrepancies between prehistoric naiad populations and those recorded by early workers such as Ortmann and Wilson and Clark. Selective collecting or gathering by the Indian may also have been a factor, as well as changes in mussel habitat brought about by flooding and other natural factors through time. Additional collections of shells from archaeological middens along the Cumberland River are needed in order to obtain a more accurate record of the abundance and species composition of the naiads during prehistoric times.

Impoundment of the middle Cumberland River has, by increasing water depth and altering the substrate, apparently proved beneficial for the establishment and/or increase of a few naiad species. To illustrate, no specimens of *Megalonaias gigantea* were recovered in the aboriginal midden deposits, but it is a common species in the river today and individuals comprised between 27 and 60 percent of the specimens taken from the three beds sampled with a brail (see Table 1). The percent of individuals of *Pleurobema cordatum* taken in these same beds varied from 15 to 32, while only five specimens (<1 percent) were recovered in the archaeological sites. *Plagiola lineolata* is presently a common species in the middle and lower Cumberland River reservoirs (5 to 7 percent of the brail samples), yet no valves of this mussel were found in the two rock shelter sites. Of the three species of *Quadrula* that inhabited the shoal and riffle areas in prehistoric times, two *(Q. pustulosa, Q. metanevra)* appear to have adjusted to and are thriving under impoundment conditions. Specimens of *Q. cylindrica* are rarely taken by the commercial shellers and although individuals of *Q. quadrula* are occasionally encountered, populations of this species appear to be low and/or localized. Although impoundment has proved favorable for several naiad species, populations of at least 25 other species were eliminated or reduced to a few remaining relic individuals as a probable result of the destruction of former riffle and shoal habitat.

ACKNOWLEDGMENTS

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Specimens obtained during this study are housed in the collections of the Zooarchaeology Section, Department of Anthropology, the University of Tennessee, Knoxville. Voucher specimens of *L. orbiculata* and *E. sulcata* have been deposited in The Ohio State University Museum, Columbus, and *(E. sulcata)* in the Museum of Comparative Zoology, Harvard University, Cambridge.

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THE SYSTEMATIC POSITION OF *COUTHOUYELLA* (GASTROPODA: EPITONIIDAE)

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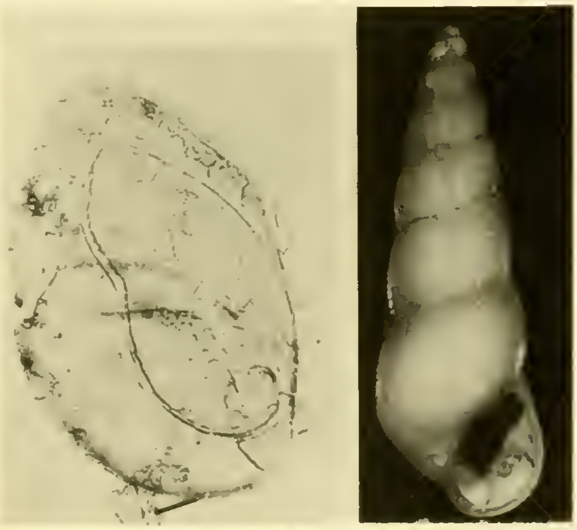
ABSTRACT

The gross morphology of Couthouyella striatula *(Couthouy, 1838) is examined. It has a broad, short proboscis-sheath, several tubular glands surrounding both the buccal mass and anterior oesophagus, and a ptenoglossate radula equipped with a plough-shaped central tooth. No penis was found. It is therefore concluded that C.* striatula *should be placed in family Epitoniidae, instead of Eulimidae or Pyramidellidae, where it has been placed previously.*

During a revision of the genera of the family Eulimidae, the anatomy of *Couthouyella striatula* (Couthouy, 1838) was examined. Results of this examination make it impossible to retain *Couthouyella* in any of the families where it has been placed previously.

Couthouy (1838) described *C. striatula* in the genus *Pyramis* Brown, 1827 (non Schumacher, 1817) a genus that presently is considered a synonym of *Cerithiopsis* Forbes and Hanley, 1849. The type locality of his material was: Fish stomachs, off Cape Ann, Massachusetts and the types are in the Museum of Comparative Zoology (no. 125 507).

Bartsch (1909) described the genus *Couthouyella* for the single species *Pyramis striatula* and stated that it had no radula. He placed the new genus in Pyramidellidae.



FIGS. 1-2. 1, *(right)* Couthouyella striatula, *shell, 12.5 mm. Maine.* 2, *(left)* C. striatula, *operculum.*

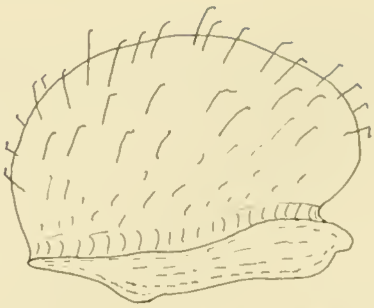
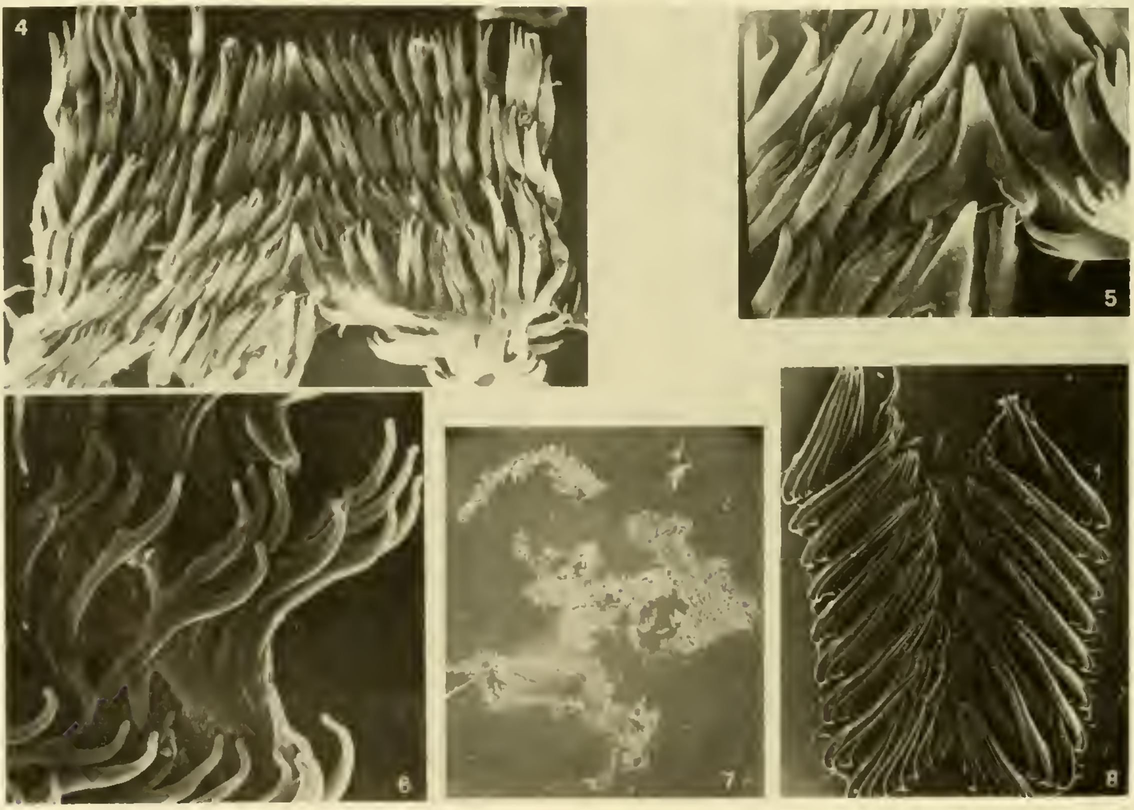


FIG. 3. Couthouyella striatula, *egg capsule, diameter 0.9 mm.*

Thiele (1931) transferred the genus to the family Eulimidae, without explanation, a position that has been accepted by later authors.

Material examined: The anatomical investigation was carried out on a sample containing some dried animals, from Massachusetts. The sample originated from the Henderson collection in U.S. National Museum of Natural History. The specimens had never been fixed, only dried, so the upper part of the animals was completely rotten, but the body whorl had evidently dried before starting to rot. A hole was made on the back side of the body whorl and the specimens were soaked in water and detergent for a day. The animals were taken out from the shell and stained with carm alum and differentiated in 1% hydrochloric acid. They were then dissected under a binocular microscope.

Results: The operculum is thin, transparent and light-brown. It has a curved rib running more or less parallel with the edge (Fig. 1). The foot is short and broad. The head is broad and the tentacles are widely-spaced. Two large black eyes are present. No penis was found in any of the six specimens (4 - 10 mm high) examined. Numerous gill lamellae could be seen on the mantle, which had been discolored purplish, by the hypobranchial gland (a characteristic of the Epitoniidae). A female gonoduct is present in



FIGS. 4-8. 4, Couthouyella striatula, *part of the radula. 0.155 mm broad.* 5, C. striatula, *detail of the central teeth.* 6, Acirsa eschrichti *(Moller)* (=A. costulata *(Mighels & Adams) (not* Turritella costulata *Borson)). Detail of teeth.* 7, A. eschrichti, *radula (fragmentary).* 8, Opalia wroblewskii *(Mörch). Half the radula. Breadth 1.1 mm.*

specimens higher than 6 mm. The alimentary canal consists of a proboscis sheath, buccal mass, oesophagus and a stomach. The proboscis sheath is short, muscular and broad. It is not easily differentiated from the buccal mass, probably because it was not possible to remove the tubular salivary glands winding around it. These also cover the buccal mass and the foremost part of the oesophagus. It was not possible to see where these glands opened into the canal, because the tissues were so brittle that they broke as soon as I tried to disentangle the coils. Nor was it possible to see any ganglia. The radula is figured in figs. 4-6. The oesophagus is lined by a thin cuticle. In front of the radula, there are two rodlike stylets that are shorter and broader than those showed by Fretter & Graham (1962, Fig. 101). The oesophagus leads to a rather voluminous stomach, that has strongly folded walls. The oesophagus and stomach were examined for contents, but nothing was found. Numerous egg capsules were attached to the shell (Fig. 3). Each capsule contains a single, shell-less embryo of 0.7 mm diameter, which agrees with the diameter of the larval shell of *Couthouyella*. These are possibly *Couthouyella* egg capsules. I am not aware that similar egg capsules have been described.

Discussion: Most details of the anatomy agree with what is known about the family Epitoniidae (Fretter & Graham 1962, Taki 1956, 1957, Thiele 1928). The only exception is the radula. The shape of the teeth and the presence of a central tooth are different from previously known epitoniids. I give figures of the two main types of radulae in Epitoniidae (Figs. 6-8) for comparison. There is no doubt that the radula of *Couthouyella* is ptenoglossate. The presence of a central tooth is probably a primitive trait retained in this genus. Therefore I do not hesitate to place *Couthouyella* in the family Epitoniidae.

Although the egg capsules believed to belong to *Couthouyella* differ considerably from those known of other epitoniids (Fretter & Graham 1962), it should be remembered that *Couthouyella* has direct development, (judging from the larval shell), while the epitoniids from which the spawn is known have planktotrophic development and much smaller larvae.

C. striatula resembles some fossil epitoniids, e.g. "*Scalaria*" *pusilla* v. Koenen, 1891 and *Acirsella inermis* (Deshayes, 1861) from the German Lower Oligocene and the French Eocene.

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I want to direct my thanks to Drs. Richard S. Houbrick and Joseph Rosewater, Division of Mollusks, U.S. National Museum of Natural History, for making the collections there available to me and for providing me with working facilities during several stays there.

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RECENT DEATH

America's oldest malacologist, Emery Perkins Chace, died on May 15, 1980, at the age of 98, in California. He was Curator of Mollusca at the San Diego Society of Natural History from 1954 to 1967, and was a beloved friend to many American amateur and professional malacologists. He was born July 31, 1882, in Warren, Rhode Island. His wife, Elsie Margaret (Herbst) was also an ardent conchologist, and died in 1975.

CRAB-CRUSHING OF PERIWINKLE SHELLS, *LITTORINA LITTOREA*, FROM TWO ADJACENT GEOGRAPHICAL PROVINCES

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ABSTRACT

Vulnerability to crab-crushing of shells of Littorina littorea *from two adjacent geographical provinces was examined. Shells from north of Cape Cod are more vulnerable to crushing by* Cancer borealis *than those of a similar size from south of Cape Cod. Northern shells are considerably thinner than southern shells, and are also weaker. A more widespread correlation between geographical position and shell thickness is also observed. I hypothesize that the difference in thickness and strength is responsible for the observed difference in vulnerability to crushing. A negative correlation between water temperature and shell thickness is a probable reason for the difference in thickness between northern and southern shells.*

In recent years, much attention has been given to the effects of predation in marine ecosystems. One interesting aspect is the predation on mollusks by crabs. Much experimental work has been done in this field. For example, British researchers (Ebling *et al.*, 1964; Kitching *et al.*, 1966; Muntz *et al.*, 1965) have described predation by *Cancer pagurus* (L.), *Carcinus maenas* (L.), and *Macropipus puber* (L.) on *Thais lapillus* L., *Mytilus edulis* L., and other mollusks. Hamilton (1976) describes predation by *Callinectes sapidus* Rathbun on *Littorina irrorata* (Say, 1822), in Florida. Rossi and Parisi (1973) describe predation by *Eriphia verrucosa* (Forskål) on six species of mollusks in Italy. A more complete review of the literature pertaining to crab predation on mollusks can be found in Vermeij (1977).

Vermeij (1976) has shown that the latitudinal gradient in gastropod shell shape is correlated with the shell's vulnerability to crab predation; specifically, there is in the tropics a greater emphasis on antipredatory features. Additionally, Caribbean shells were found to be more vulnerable to crushing by Indo-Pacific crabs than were Indo-Pacific shells. (see also Zipser and Vermeij, 1978).

The present study, a specific example of the above correlation, examines the vulnerability of *Littorina littorea* (L.) shells from two adjacent geographical provinces to crushing by *Cancer borealis* (Stimpson, 1859). *Cancer borealis* commonly occurs with *Littorina littorea* throughout New England, and is expected to feed on the snail in the field (G. J. Vermeij, *pers. comm.*). Other predators of *L. littorea* include *Carcinus maenas* (L.) (Pettitt, 1975; Lubchenco, 1978), *Homarus americanus* (Squires, 1970), *Thais lapillus*, the fish *Tautogolabrus*, and the gull *Larus argentatus*. In this study, *C. borealis* is being used as a "model" predator.

The two geographical provinces considered here are the boreal province (northern), and the Virginian sub-province (southern). These two provinces form a geographical boundary at Cape Cod, Massachusetts. It is hypothesized that the southern shells are less vulnerable to predatory crushing than are the northern shells, because of the previously mentioned correlation between latitudinal gradient of the shape of a gastropod shell and the shell's vulnerability to crab predation. (see also Vermeij, 1978).

MATERIALS AND METHODS

Three specimens of *Cancer borealis* were netted in approximately 18 meters of water in the Minemsha area of Martha's Vineyard Island. The

TABLE 1. *Weight, Size, and Sex of the 3* Cancer borealis.

Crab	Weight (wet)	Width	Sex
1	300.1 gm.	108.1 mm.	female
2	300.0 gm.	125.2 mm.	male
3	331.5 gm.	126.5 mm.	male

weight, size, and sex of each crab were recorded (Table 1). Individual crabs were maintained in separate tanks of approximately 15 liters capacity that were continuously aerated. The bottoms of the tanks were covered with approximately 5 centimeters of gravel to provide the crabs with a natural habitat.

Littorina littorea shells inhabited by hermit crabs of the species *Pagurus longicarpus* (Say, 1817) were collected from two localities: Woods Hole on the south side of Cape Cod, and Barnstable Marsh on Cape Cod Bay, on the north side of Cape Cod. Shells collected from Woods Hole were taken from rocky substrates, while shells taken from Barnstable Marsh were taken from clusters of rock surrounded by sand. An effort was made to take only shells in good condition. The hermit-inhabited shells were maintained in tanks of approximately 10 liters capacity that were continuously aerated. The size of each shell was measured with Vernier calipers before experimentation.

Prior to experimentation, the crabs (*Cancer borealis*) were acclimatized to their new environment for two days. After this time, the prey, composed of six hermited shells from either Barnstable Marsh or Woods Hole, were added to each of the tanks. Shells were placed in the tanks at three in the afternoon, and at eight the following morning shell fragments and any remaining prey were removed from the tanks. The afternoon of the following day, the experiment was repeated. A total of six experiments was performed, three in which six southern hermited shells were given to each of the crabs, and three experiments in which six northern hermited shells were given to each of the crabs. Thus, each crab was offered a total of thirty-six hermited shells.

RESULTS

Results of the six experiments are given in Table 2. Observations of the crab attacks on the shells showed that, in many cases, the crab started crushing the shell by breaking the lip of the shell, and continued crushing along the body whorl. Because of this method of attack, in some cases the hermit crab was small enough to retreat farther back into the shell. Therefore, in the following analysis, the binomial distribution test was performed twice, once considering as crushed all shells attacked by the crabs, and once considering as crushed only shells in which the hermit crab was eaten.

Overall, more northern shells were attacked than southern shells. Assuming as null hypothesis that the probability is equal for northern or southern shells to be crushed, a binomial distribution test considering all shells attacked as successfully crush gives a set of three significance levels, one associated with each crab's ability to crush northern shells; these levels are 0.4119, 0.0898, and 0.0929. When these levels are combined by Fisher's combination of significance method (Birnbaum, 1954), the overall level of significance associated with rejecting the null hypothesis is less than 0.07. The same binomial test considering as crushed only shells in which the hermit crab was eaten again gives a set of three significance levels (0.0112; 0.125; and 0.2112), which when combined as before give an overall significance level associated with rejecting the null hypothesis of less than 0.02.

These results of the binomial distribution tests show that there is indeed a significant statistical

TABLE 2. *Lengths of shells of* Littorina littorea *offered to the crabs. An asterisk indicates that the shell was attacked.*

Experiment	Lengths of Shells Offered (mm.)	Origin of Shells
1. Crab 1	14.3, 16.2, 16.6, 19.0, 20.0, 22.0	Woods Hole
Crab 2	14.8, 15.9, 17.7*, 18.0, 18.1, 18.1	Woods Hole
Crab 3	15.5, 17.5, 18.4, 19.6, 22.5, 25.0	Woods Hole
2. Crab 1	19.1*, 19.2*, 19.3*, 19.8*, 20.1*, 23.3*	Barnstable Marsh
Crab 2	17.1*, 19.1, 19.9, 20.0, 20.1*, 20.1*	Barnstable Marsh
Crab 3	19.0*, 19.6*, 19.8*, 20.0*, 21.0*, 21.7*	Barnstable Marsh
3. Crab 1	16.6*, 18.1*, 18.2*, 18.8*, 19.5, 23.3*	Barnstable Marsh
Crab 2	17.1*, 17.8*, 19.1*, 20.9, 21.0, 24.5*	Barnstable Marsh
Crab 3	14.8*, 16.5*, 16.6*, 18.6*, 22.7*, 25.6*	Barnstable Marsh
4. Crab 1	15.9, 20.4*, 21.5, 22.0*, 22.2*, 22.8	Woods Hole
Crab 2	16.5*, 18.4, 20.2, 23.5, 23.5, 25.7	Woods Hole
Crab 3	13.3, 14.8*, 15.8, 17.3*, 20.4*, 21.1*	Woods Hole
5. Crab 1	15.1*, 15.4*, 17.3*, 18.5*, 21.8*, 24.0*	Woods Hole
Crab 2	17.6, 18.5, 18.6, 20.4, 23.5, 24.5	Woods Hole
Crab 3	16.4*, 17.0*, 17.3*, 18.0*, 20.0*, 21.0*	Woods Hole
6. Crab 1	15.5, 16.9, 17.8, 17.9, 19.1, 24.7	Barnstable Marsh
Crab 2	15.7, 16.5, 17.1, 17.3, 18.4, 18.4	Barnstable Marsh
Crab 3	17.7*, 18.2*, 19.0*, 19.5*, 21.0*, 21.1*	Barnstable Marsh

difference in the vulnerability of hermited shells from the two localities studied to crab crushing. Shells from Barnstable Marsh were more vulnerable to crushing than were shells from Woods Hole. This difference in vulnerability could be due to many factors.

One possible factor is shell length. Wilcoxon's rank sum test was used to examine this possibility. Application of this test showed that the crabs generally tended to attack smaller shells regardless of the geographical origin of the shells ($P<0.14$). There was no substantial difference in the mean size of the overall sample of shells offered from the two localities.

Another possible factor is shell thickness. Shells from both geographical localities that had been attacked but not completely destroyed in the experiments were measured for thickness with Vernier calipers. Points at which measurements were taken were similar for all shells, the farthest point back on the crushed lip. Twenty-five attacked specimens from each geographical locality were measured. The mean thickness of the crushed lip of the northern shells was 0.59 mm, and that for the southern shells was 0.70 mm. Shells from Barnstable Marsh were, on the average, 16 percent thinner than shells from Woods Hole.

An effort was made to determine whether the observed variation in shell thickness was a more widespread geographical phenomenon, reflecting a north to south trend. The length and thickness of shell specimens from twenty-one additional *Littorina littorea* populations along the Atlantic seaboard were measured, using the collections of Geerat Vermeij and the United States National Museum. Points of measurement of shell thickness were at the midpoint of the lip as far into the shell as the calipers could reach. Wilcoxon's rank sum test was then applied to these data. In the 18-19 mm size range, shells from populations north of Cape Cod were significantly thinner than shells from populations south of Cape Cod ($P<0.001$). A second application of the test in the 22-23 mm size range gave similar results ($0.001<P<0.005$).

Professor J. D. Currey has measured the strength of shells of *Littorina littorea* collected alive from Barnstable Marsh and from Woods Hole. He measured the load that is required to break a shell between two smooth metal plates. The shells were oriented so that the aperture faced down on the lower plate. The upper plate touched the dorsal portion of the body whorl. Shells from Barnstable Marsh were found to be significantly weaker than shells from Woods Hole ($P<0.05$). Currey also found that shells from Barnstable Marsh have a significantly higher volume/mass ratio; that is, they are thinner ($P<0.02$). These data are in accordance with the geographical pattern observed in shell thickness.

TABLE 3. *Shell Length and Thickness of Additional* Littorina littorea *Populations (in mm.)*

Locality	*Length (Mean)*	*Range*	*Thickness (Mean)*	*Range*
1. Placentia Newfoundland	18.0	17.3-19.5	0.87	0.8-1.0
2. Halifax Co., Nova Scotia	18.0	15.5-21.4	0.68	0.5-0.9
3. Biddeford, Maine	19.7	18.5-20.5	0.62	0.5-0.7
4. Squirrel Island, Maine	21.1	17.7-24.7	1.45	1.3-1.6
5. Squirrel Island, Maine	25.0	22.1-27.2	1.68	1.5-1.9
6. Hampton Beach, N.H.	19.3	16.8-22.8	0.83	0.6-0.9
7. Nantucket Island, Mass.	23.9	22.0-26.4	0.97	0.6-1.2
8. Cohasset, Mass.	20.7	19.0-22.9	0.86	0.7-1.0
9. Yarmouth Port, Mass.	21.2	19.2-23.5	0.86	0.6-1.2
10. Saugatuck, Conn	19.8	15.6-27.3	0.78	0.5-1.1
11. Noank, Conn.	24.0	20.7-26.0	1.60	1.1-1.9
12. Noank, Conn.	22.5	21.3-23.5	1.30	1.2-1.6
13. Wesport, Conn.	18.2	14.2-21.0	1.30	1.2-1.6
14. Double Beach, Conn.	20.3	18.7-24.1	1.30	1.2-1.4
15. Double Beach, Conn.	20.0	19.2-21.4	0.90	0.7-1.1
16. Double Beach, Conn.	18.0	17.1-19.2	0.70	0.4-0.9
17. Guilford, Conn.	18.4	16.3-21.8	1.20	1.0-1.4
18. Guilford, Conn.	18.3	16.8-19.3	0.87	0.7-1.0
19. Tuckerton Meadows, N.J.	22.6	19.6-26.3	1.00	0.8-1.4
20. Tuckerton Meadows, N.J.	22.7	20.8-24.8	1.50	1.2-1.7
21. Tuckerton Meadows, N.J.	21.1	19.6-23.8	1.50	1.3-1.7

DISCUSSION

It is apparent that shells from Barnstable Marsh are more vulnerable to crab crushing than are shells from Woods Hole. This is probably due to the fact that the northern shells are considerably thinner than the southern shells, as shown by Currey's data and the data on shell lip thickness. Because shell strength is directly proportional to the square of the shell thickness (Wainwright *et al.*, 1976), the 16 percent difference in thickness between the northern and southern shells will translate into a much greater difference in strength.

A basic assumption of the experiments was

that shells inhabited by hermit crabs are not intrinsically different than living shells. (Living shells were not used in the experiments because of the mollusk's tendency to crawl out of the aquaria.) This assumption is substantiated by the fact that only shells in good condition were used in the experiments, and by the results obtained by Currey demonstrating that the differences between northern and southern shells in maximum sustainable load to crushing are not artifacts of differential erosion or other processes that occurred after the death of the snail. There is also no difference in shape between living shells and shells inhabited by hermit crabs. All indications are that there is indeed a difference in shell strength between the two populations. The northern shells are structurally weaker than are the southern shells, and are thus more vulnerable to crushing.

There are several possible reasons for the difference in thickness between the northern shells and the southern shells. One is that epizooid growth, which is more pronounced on shells from Barnstable Marsh, might inhibit shell secretion by the mollusk, and thus cause the shell to be thinner. Epizooid growth might also decrease shell strength through destruction of the shell.

Secondly, it is possible that the difference in shell thickness is due to a difference in habitat. Shells from two different habitats were used in the experiments, rock and sand. At present, insufficient collections are available to resolve this question.

Results from the measurements of shell thickness and length of additional *Littorina littorea* populations along the Atlantic seaboard indicate that there is a significant relation between geographical position and shell thickness. This relation is a north to south trend, with shells increasing in thickness as populations move farther south. The observed variation in thickness between shells from Barnstable Marsh and shells from Woods Hole is consistent with this trend. The probable reason for this is that Barnstable Marsh is farther north and in a different current regime than Woods Hole, and is therefore colder. Colder waters appear to inhibit calcification in mollusks and other skeletonized invertebrates (Vermeij, 1977; Vermeij, 1978).

This inhibition of calcification may be reflected in *Littorina littorea* by a decrease in the amount of shell secretion. Thus, shells inhabiting Barnstable Marsh, existing in a colder environment than shells in Woods Hole, exhibit the negative correlation between water temperature and shell thickness, and are thinner than the Woods Hole shells. It is important to realize that this may reflect a temperature dependence of biochemical processes, and does not necessarily imply a genetic difference between the northern and southern populations. This is especially true in light of the fact that *Littorina littorea* is a relative newcomer to the east coast of the United States (Bequaert, 1943), and may not have had time to undergo genetic differentiation between populations.

ACKNOWLEDGMENTS

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LYMNAEA (PSEUDOSUCCINEA) COLUMELLA IN COLOMBIA[1]

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ABSTRACT

Lymnaeid snails collected from several localities in Colombia conformed with the North American Lymnaea (Pseudosuccinea) columella. *They differ from the South American* Lymnaea cousini, *but* Lymnaea bogotensis *and* L. peregrina *are regarded as synonyms. The present geographical distribution of* L. (P.) columella *is discussed, as well as the disease vector capacity of the snails from Colombia.*

Information is scanty about lymnaeid snails in South America. From the few reports it is realized that there is a great need for the stabilization of the systematics of this group. Recently, the authors had the opportunity to collect and examine lymnaeid snails from several localities in Colombia, and to compare them to other reported lymnaeids in South, Central and North America. On the basis of the morphology of the shell and soft parts of the snails from Colombia we regard them as *Lymnaea (Pseudosuccinea) columella* (Say). Biochemical and serological methods in taxonomy may reveal differences not evident in morphological studies.

The snails from Colombia have a succinidform shell with a short spire and four whorls. These are well-rounded and rapidly enlarging, the body whorl being about three times the size of the rest of the shell. The shell is thin, horn color and is shiny on the surface. The axial sculpture is coarse and the spiral sculpture is fine and microscopic. The large, ovate aperture is expanded at its lower portion. The peristome is thin and sharp. The inner lip adheres to the body whorl and is reflected over the umbilicus, either completely closing it or leaving a small chink. The animal is black in field-collected specimens but is light and mottled with a few black dots in laboratory-reared specimens. The lateral teeth of the radula are tricuspid and the marginal are serrated. The length of the vergic sac is only about one third or less of the length of the preputium. The penis is simple, short and is elongate pyriform. The preputium has thick walls and a large sarcobelum. The prostate is long and cylindrical with the proximal end somewhat enlarged. The albumin gland is large and kidney-shaped. The oviduct is large and is almost round. The spermatheca is small, globular, and its duct is long and thin.

The snails from Colombia are evidently widely distributed at least in the Departments of Valle, Cauca, Meta and Nariño. They were located in the following localities: Department of Valle:

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Gorgona swamp, 20 km northeast of Cali; Vijes, 40 km north of Cali; Ponce; beyond Ponce; 10 km east-northeast of Palmira; Lake Calima about 50 km north of Cali; Bugalagrande, and Buga. Department of Cauca: Road to Popayan, about 40 km south of Cali. Department of Meta: at Villavicencio. Department of Nariño: Laguna de la Cocha, and El-Mira about 40 km east of Tumaco.

Geographical Range

The type locality of *L. (P.) columella* (Say, 1817) is probably near Philadelphia, U.S.A. According to Baker (1928), its general distribution extends over the eastern and midwestern states, ranging from Nova Scotia westward to Minnesota, Kansas and Texas, and from Manitoba and Quebec southward to Texas, Mississippi and Florida. In addition, the senior author has collected this snail in Michigan, North Carolina and Louisiana, and Panama, and has specimens from Costa Rica.

In tropical America the general distribution of *L. (P.) columella* seems to be in various countries of Central America and in Venezuela, Paraguay and Argentina in South America. According to the present report it occurs in Colombia. *Lymnaea peregrina* Clessin, 1882, whose type locality is Taguara del Mundo Novo, Brazil, has been found to have shell and animal characteristics identical with those of *L. (P.) columella* (Hubendick, 1951). Moreover, *L. peregrina* collected by the senior author from several localities in Minas Gerais, Brazil, were examined morphologically and found to be similar to *L. (P.) columella*. The distribution of *L. (P.) columella* (syn. *L. peregrina*) in South America according to Hubendick (1951) is as follows: Villarica in Paraguay, Rio Chico in southern Argentina (identified as *L. andeana* Pilsbry), and Rio Camaguam in Rio Grande do Sul, Brazil. There have been no records of lymnaeids from the northern part of Brazil or from the Guianas.

The senior author (Malek and Chrosciechowski, 1964) recorded *L. (P.) columella* from Venezuela. The habitat of these snails is an aqueduct near Maracay, State of Aragua, attached to the concrete lining at the water surface and to floating sticks and debris.

As to the lymnaeids of Colombia Pilsbry (1935) reported two lymnaeid snails from Bogota viz. *Lymnaea bogotensis* (as a new species) and *L. selli* (Preston). The brief description of *L. bogotensis* and the photograph (Plate 6, Fig. 9) agree in the main with that of *L. columella* (Say). Brumpt et al. (1939-1940) relying on Pilsbry's report found *L. bogotensis* naturally infected with *Fasciola hepatica* in the Bogota savannah area of Colombia. Hubendick (1951) based on the snail photographs included in Brumpt et al. (loc. cit.) believed that their snail *L. bogotensis* was *Lymnaea cousini* Jousseaume 1887.

Hubendick (1951) dealt with the morphology and geographical distribution of *Lymnaea cousini* Jousseame 1887 (type locality, Chanchu-Yacu, Chilogallo, Quito, Ecuador), and its synonym *L. ubaquensis* Piaget, 1914 (type locality Laguna Ubaque, Cundinamarca, Colombia). He stated that *L. cousini* seems to extend from Valdivia in southern Chile to the region of Bogota in Colombia. The genitalia of *L. cousini* as described by Hubendick differ from those of our Colombian specimens. In *L. cousini* the preputium has dark spots. The velum and sarcobelum are small and the vergic sac is long; is only slightly shorter than the preputium.

L. (P.) columella is believed to have been introduced by human agency, probably with aquatic plants into Puerto Rico, South Africa, Australia, New Zealand, and many European countries. In Europe *L. (P.) columella* has been reported only in botanical hothouses, but in South Africa it occurs in many natural and artificial habitats, throughout the Republic from the Eastern Transvaal to Western Cape Province. It appears that *L. columella* is particularly common in the neighborhood of all the major ports.

In South Africa *L. columella* has in many areas become one of the most abundant freshwater mollusks, (van Eeden and Brown, 1966). The latter authors believe that one factor contributing to its success after being introduced may be the ability of the snails to exist on moist mud often several centimeters away from free water. It can also lead a submerged existence together with several other indigenous species including *Lymnaea natalensis* Krauss. Its introduction in South Africa is of veterinary significance

because *L. columella* from Durban has already been successfully infected with South African strains of both *Fasciola hepatica* Linn. and *F. gigantica* Cobbold and cercariae recovered (Swart, in van Eeden and Brown, 1966). In New Zealand *Lymnaea (Pseudosuccinea) columella* is considered as a rapidly colonizing species and fascioliasis became more widespread following its introduction (Pullan, 1969, Pullan et al., 1972).

In Australia *L. (P.) columella* has been found during the last few years in Sydney, Brisbane, Melbourne, and Perth either in parks, aquaria, and aquatic plant nurseries or creeks in the metropolitan areas (Boray, 1978; Ponder, 1975; Salisbury et al., 1976). Boray (1978) found that *L. (P.) columella* is susceptible to the Australian *F. hepatica* and produces relatively large numbers of metacercariae. He is of the opinion that *L. (P.) columella* could have a substantial role as an intermediate host in irrigation districts of Australia. The distribution of this and other aquatic *Lymnaea* spp. could be of great importance in Australia in areas where the semiamphibious *L. tomentosa* does not occur at present, such as in apparently suitable habitats in some districts of Western Australia.

Vector Capacity

Using miracidia of the liver fluke *Fasciola hepatica* from Louisiana laboratory-reared specimens of *L. (P.) columella* from Colombia became infected with this fluke. The results indicate that they are the hosts, or one of the hosts, of this fasciolid in Colombia. Another group of snails also became readily infected with *Heterobilharzia americana*, a mammalian schistosome in southern United States. The degree of their infection was similar to that of *L. (P.) columella* from Louisiana. In a third group of snails from Colombia double infections were obtained of *F. hepatica*, and *H. americana*.

The high susceptibility of the snails from Colombia to *F. hepatica* and *H. americana* supports the morphological similarities between them and *L. (P.) columella* from Louisiana.

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NEWS

Dr. Tadashige Habe, well-known Japanese malacologist, has retired from his curatorial position at the National Science Museum in Tokyo, after many years of distinguished service. He continues his editorship of *Venus* and is now active as a Professor of Zoology at Tokai University.

Dr. Takashi Okutani has been promoted to Senior Curator, and will carry on Dr. Habe's traditions in the Department of Zoology, National Science Museum, Tokyo. Dr. Okutani graduated from the Tokyo University of Fisheries in 1954, and did research at the Tokai Regional Fisheries Research Laboratory on the taxonomy and life-history of deep sea mollusks, especially cephalopods. He spent two years doing research at the Scripps Institute of Oceanography in 1961 and 1970-71.

A NEW *FALSILYRIA* (VOLUTIDAE) AND A NEW *CONUS* (CONIDAE) FROM ROATAN ISLAND, HONDURAS (ATLANTIC)

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Recent increased collecting off the coast of Roatan Island, Honduras, (approximately 16°20'N, 86°15'W) has brought to light a number of unusual and atypical Caribbean gastropods. The fauna of this area, containing such species as *Falsilyria demarcoi* (Olsson, 1965), *Pleioptygma helenae* (Radwin and Bibbey, 1977), and *Turbinella scolymoides* (Dall, 1890) (E. Vokes, 1966), more closely resembles the fauna of the Pliocene Caloosahatchee Formation of Florida than it does the modern Caribbean Molluscan Province (E. Vokes, 1966:63). In essence, the molluscan assemblages of the Recent Bay of Honduras most probably represent pockets of Pliocene relicts that, in turn, derived from the Tertiary faunas of the southeastern United States.

The archaic nature of the Roatan Island fauna is further reinforced by the recent discoveries of the second known living species of *Falsilyria* and an unusual new species of shallow water *Conus*. These interesting new Caribbean gastropods are herein described.

FAMILY Volutidae

Genus *Falsilyria* Pilsbry and Olsson, 1954

Falsilyria morrisoni new species

(Figs. 1-6)

Shell description: Shiny, highly polished; body heavy, thickened, with 4 to 5 whorls; body whorl with 7 to 12 rounded major axial ribs and 30 to 60 sharply defined minor axial ribs; spire elevated, turriculate; shoulder angled with blunt coronations; spire whorls with 3 or 4 raised, beaded spiral cords; protoconch large, with 3 bulbous, smooth whorls; aperture elongate, roughly ⅔ of total shell length; columella with 8 or 9 major plications and 3 to 6 minor plications; plications heavily beaded; outer lip thickened and flaring in adults; color of base of shell salmon-pink to rose-red with 6 to 8 evenly-spaced revolving bands of alternating black and white spots; base color overlaid with numerous fine red-brown specklings and scattered large dark brown blotches; protoconch salmon-orange; interior of aperture pale pinkish white turning white toward outer lip; columellar region and plications salmon-pink; outer lip white with 11 to 14 raised black denticulations; operculum unknown.

Type locality: 60 m depth off north coast of Roatan Island, Honduras.

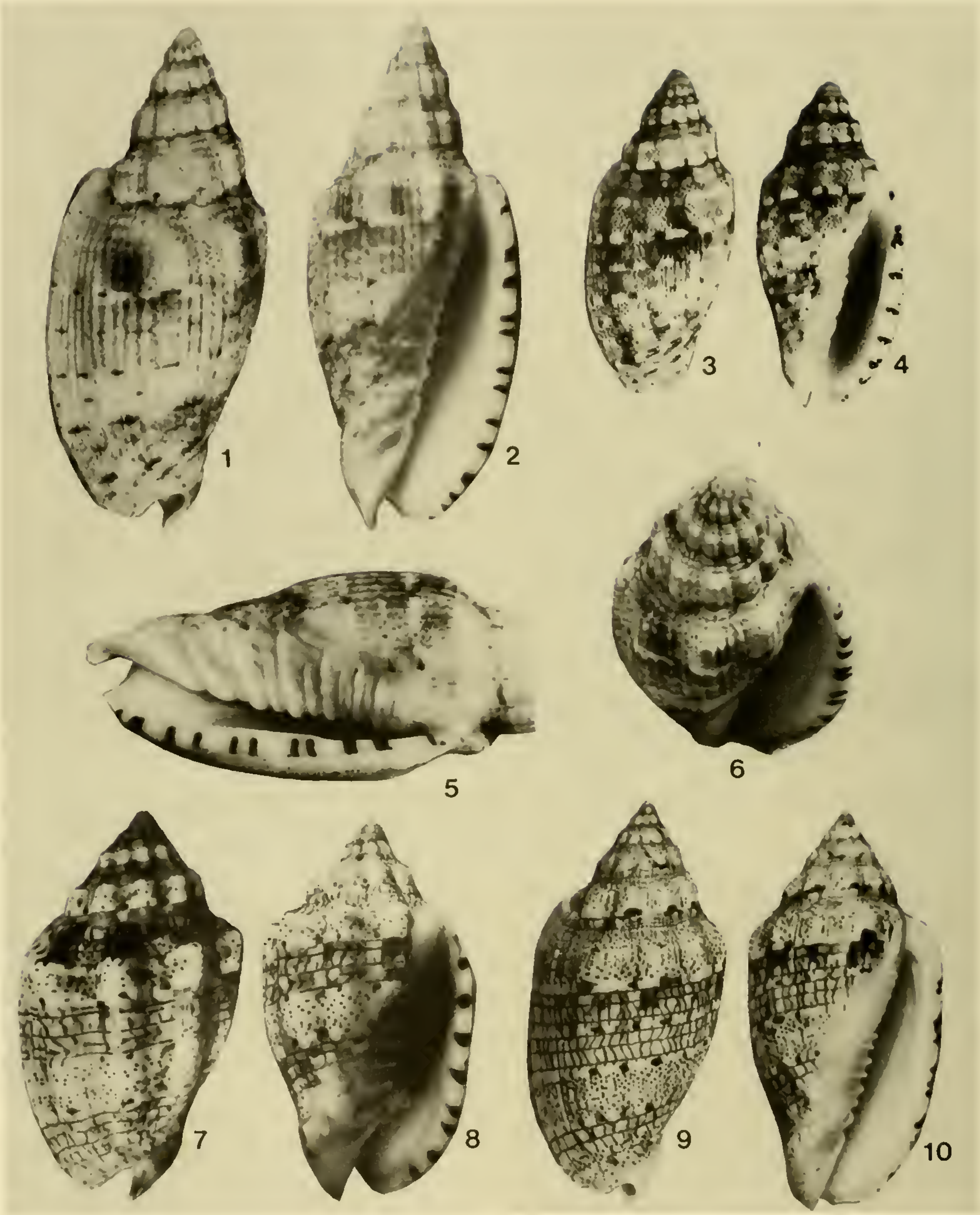
Distribution: At present, known only from off Roatan Island.

Material examined: Holotype—Length 73.4 mm, width 31.5 mm, 60 m depth off north coast of Roatan Island, Honduras, January, 1979, U.S. National Mus. Nat. Hist. No. 784485. Paratype—Length 45.4 mm, same depth, locality, and date as holotype, USNM 784486; Length 42 mm, same depth and locality as holotype, collection of Dr. Emilio F. Garcia, Lafayette, Louisiana.

Associated mollusks: Commonly taken with this species, in both lobster pots and shrimper's nets, are the following large gastropods; *Phalium granulatum* (Born, 1778), *Fusinus dowianus* Olsson, 1954, *Pleioptygma helenae, Falsilyria demarcoi, Conus cingulatus* Lamarck, 1810, *C. lorenzianus* Dillwyn, 1817, *C. spurius* Gmelin, 1791, and a large undescribed *Hindsiclava.*

Etymology: Named for Robert Morrison of Sarasota, Florida, who first recognized the species as new and who kindly donated the type material.

Discussion: The new volute is the second known living *Falsilyria* and is sympatric with the other living species, *F. demarcoi* (Figures 9 and 10) (S. Hoerle and E. Vokes, 1978:107). *Falsilyria morrisoni* differs from *F. demarcoi* by having a higher spire, more acutely angled shoulder, less numerous and heavily beaded columellar plications, and by having a larger protoconch.



FIGS. 1-10. **1**, Falsilyria morrisoni *n. sp. Dorsal aspect of holotype. USNM 784485.* **2**, Falsilyria morrisoni *n. sp. Ventral aspect of holotype. USNM 784485.* **3**, Falsilyria morrisoni *n. sp. Dorsal aspect of paratype. USNM 784486.* **4**, Falsilyria morrisoni *n. sp. Ventral aspect of paratype. USNM 784486.* **5**, Falsilyria morrisoni, *detail of columellar plications of holotype.* **6**, Falsilyria morrisoni, *detail of spire sculpture of holotype.* **7**, Voluta musica *Linnaeus, 1758. 54 mm specimen from Carriacou, Grenadines.* **8**, Voluta musica. *Ventral aspect of same specimen.* **9**, Falsilyria demarcoi *(Olsson, 1965). 70 mm specimen from Roatan Island, Honduras.* **10**, Falsilyria demarcoi. *Ventral aspect of same specimen.*

The new species lacks the bright orange or peach base color that is characteristic of *F. demarcoi* (Olsson, 1965:663). The raised, beaded cords on the spire of *F. morrisoni* (Figure 6) also separate the new species from the smooth-spired *F. demarcoi.* The beaded columellar plications of *F. morrisoni* (Figure 5) more closely resemble the beaded plications of the fossil *F. mansfieldi* (Dall, 1916) (S. Hoerle and E. Vokes, 1978: pl. 4, figs. 4a, 5) than they do those of the living *F. demarcoi.* Conversely, the smoothly plicated *F. demarcoi* is closer to the fossil *F. anoptos* S. Hoerle and E. Vokes, 1978 than it is to the new species.

The genus *Falsilyria,* though resembling the genus *Voluta,* differs in having more numerous columellar plications, and in the case of *F. morrisoni,* beaded plications. As pointed out by Hoerle and Vokes (1978:107), the two genera represent parallel evolution from a common ancestral stock. *Voluta* s.s. is restricted to the southern Caribbean, both in Recent and fossil assemblages, while *Falsilyria* is known primarily from fossil deposits in the southeastern United States. The latter is now restricted to the northernmost Caribbean, specifically the Yucatan Peninsula and Gulf of Honduras areas. For comparison of the two genera, a typical specimen of *Voluta musica* Linnaeus, 1758 from Carriacou, Grenadines, Lesser Antilles, is shown in Figures 7 and 8.

FAMILY Conidae

Genus *Conus* Linnaeus, 1758

Conus kulkulcan new species

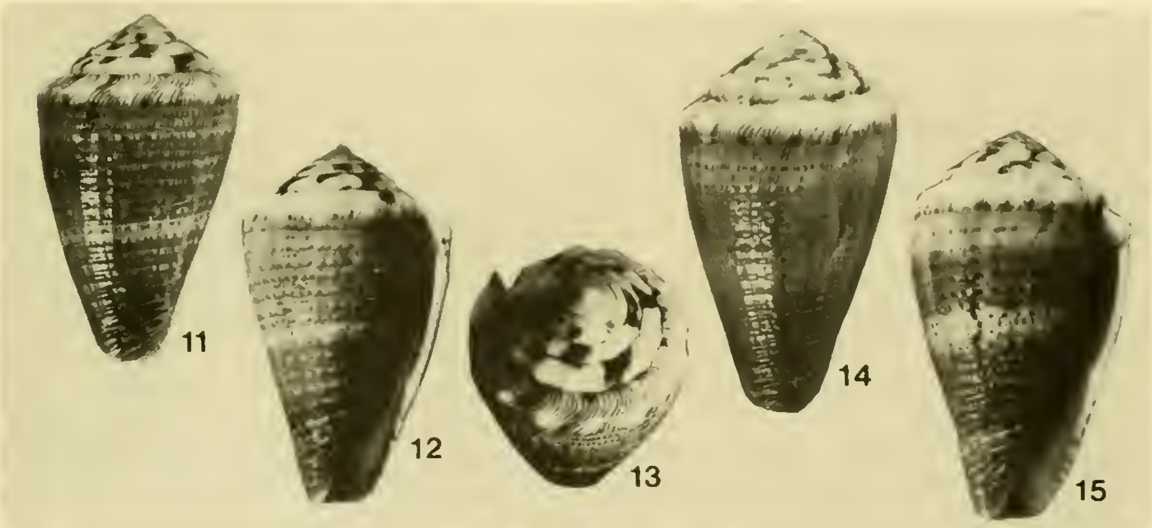
(Figs. 11-15)

Shell description: Squat, shiny, with strongly coronated shoulder; body with 6 whorls; shell sculptured with 15 to 20 raised, pustulated spiral cords, becoming coarser on anterior end; spire smooth; shell color blue-gray with two wide dark gray-brown bands, one above shell midline, one below; raised spiral cords white with fine brown dots and dashes; body midline with pale blue-gray band; anterior tip dark blackish brown; spire and early whorls bright pink; spire pure white with numerous red-brown radiating hairlines; early spire whorls with large black-brown blotches; aperture deep blue-purple, becoming paler in interior; periostracum smooth, translucent yellow.

Type locality: 2 m depth on north side of Roatan Island, Honduras.

Distribution: At present, known only from shallow water near Roatan Island.

Material examined: Holotype—Length 21.3 mm, width 12.2 mm, 2 m depth, north coast of



FIGS. 11-15. **11**, Conus kulkulcan *n. sp. Dorsal aspect of holotype. USNM 784487.* **12**, Conus kulkulcan *n. sp. Ventral aspect of holotype. USNM 784487.* **13**, Conus kulkulcan, *detail of spire color pattern of holotype.* **14**, Conus kulkulcan *n. sp. Dorsal aspect of paratype.* **15**, Conus kulkulcan *n. sp. Ventral aspect of paratype.*

Roatan Island, Honduras, January, 1979, U.S. National Mus. Nat. Hist. No. 784487; Paratype—Length 22 mm, same depth, locality, and date as holotype, in my collection.

Ecology: The new species was found in sand underneath large coral boulders in 2 m of water near the shoreline. Other mollusks found with *Conus kulkulcan* included the gastropods *Morum oniscus* (Linnaeus, 1767), *Muricopsis schrammi* (Crosse, 1863), and *Vexillum dermestinum* (Lamarck, 1811), and the spinose polyplacophoran *Craspedochiton hemphilli* (Pilsbry, 1893).

Etymology: Named for Kulkulcan, feathered snake god of the Mayans. Like his nautical equivalent, Quetzalcoatl, Kulkulcan was often associated with the sea. Since Roatan was a Mayan trading center in precolumbian times, the taxon honors the indian sea god.

Discussion: At first glance, *Conus kulkulcan* would not be taken for a Caribbean species, so unusual is the color pattern. With the white coronated shoulder, blue-gray body color, black anterior tip, and deep blue aperture, the new species very closely resembles *Conus parvulus* Link, 1807 and *C. imperator* Woolacott, 1956 from the Indo-Pacific region. Small specimens of *C. biliosus* Röding, 1798 from India also resemble *C. kulkulcan.*

In the western Atlantic, only *Conus mus* Hwass, 1792, could possibly be confused with *C. kulkulcan.* The dark hairline flammules on the spire (Figure 13) and the purple-blue aperture, however, easily separate the new species from the well-known and similarly colored *C. mus. Conus kulkulcan* appears to be related to the West Indian *Conus magellanicus* Hwass, 1792—*C. cardinalis* Hwass, 1792, species complex and is the only known Central American representative of this group of small, rock-dwelling cones.

ACKNOWLEDGMENTS

I would like to thank Mr. Robert Morrison, Sarasota, Florida, and Mr. Gary Magnotte, Pompano, Florida, for the generous donation of the type material of the new species. Special thanks are given to Mrs. Sally D. Kaicher, St. Petersburg, Florida, and Mr. Gonzalo Cruzat, Miami, Florida, for the excellent photographs.

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LAEVICAULIS HAROLDI, A NEW VERONICELLID SLUG FROM NATAL, SOUTH AFRICA (GASTROPODA: PULMONATA)

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While collecting amphibians on December 23, 1977, in Durban, Natal Province, South Africa, Dr. Harold A. Dundee found some strange-looking organisms on living *Typha* leaves in an empty lot. He and a local herpetologist, Mr. Lynn Raw, originally thought they were lepidopteran larvae. Only after being collected did they extend the body and tentacles so as to be recognizable by me as veronicellid slugs. I have worked with Veronicellidae for years and these are the most bizarre ones I have ever seen. Only six specimens could be found despite an intensive effort by all three of us. This author is indebted to Mr. Raw for taking us to that locality in the course of the day's collecting.

Pictures of the living slugs were taken im-

mediately. Upon return to the United States, I searched the literature but could not find any description of these veronicellids. Dissection revealed significant differences from other known species. Pictures were sent to Dr. A. C. van Bruggen now of the University of Leiden who had long worked in South Africa. He also had not seen slugs like them before. Therefore I have elected to describe these herein and name them in honor of their discoverer, Dr. Harold A. Dundee. Type specimens were deposited in the U. S. National Museum of Natural History in Washington, D. C.

External description: Laevicaulis haroldi n. sp. (Figs. 1: a, b, c, d). Four color phases were found. This mollusk can change to any of these phases. The most distinctive one is that seen in Fig. 1c. When the animal is contracted, it looks most like a lepidopteran larva. The other 3 color phases (Fig. 1, a, b, d) seem to be a part of a transition from dark-brown to cream color. Even when the organism is in the cream stage, the anterior end, including the tentacles and the posterior, remain dark as seen in Fig. 1a. In all color phases the animal retains a "wrinkled," finely banded, appearance. Upper tentacles are light-brown with dark-brown eyes in all phases. The lower ones appear grey. The hyponotum is smooth and cream colored in all. The *sole* is the same except that it tends to be somewhat transparent.

When contracted the hyponotum takes on a mottled appearance (cream and tan) and the sole remains as in the stretched condition thus making it much more evident. The foot is typical veronicellid.

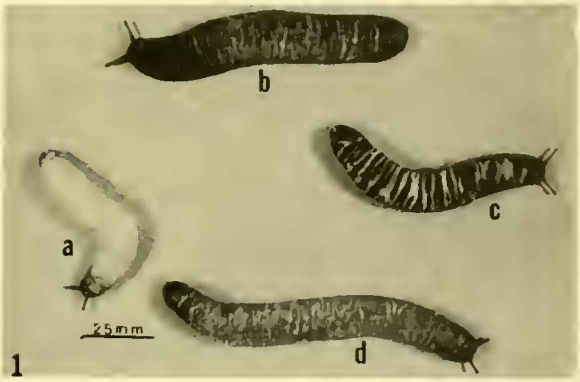

FIG. 1. Laevicaulis haroldi, *a new species of veronicellid slug from South Africa.* **a.** *cream color phase;* **b.** *darkest brown phase;* **c.** *intermediate phase;* **d.** *tan phase.*

The measurements of the six specimens were these:

	Notum Length (mm)	Width (mm)	L/W index	Hyponotum Width (mm)	Sole Width (mm)
1.	88.9	9	9.8	3	4
2.	69.9	7	9.9	3	4
3.	57.1	6	9.5	2	3
4.	76.2	10	7.6	3	3
5.	50.8	5	10.1	2	3
6.	38.1	5	7.6	1.5	3

Internal Description: A dorsal incision revealed the anatomical arrangement shown to be that of *Laevicaulis* Simroth (see Forcart, Plate V, Fig. 8a, 1953). Diagnostic characteristics of this genus include a rounded anus situated submedially and the female genital pore located in the posterior half of the hyponotum. Also the anterior delimitation of the intestines is formed by a fold of the intestinal tract.

Two species of *Laevicaulis* are known from Durban: *Laevicaulis natalensis natalensis* (Krauss), *L. natalensis brauni* (Simroth) and *Laevicaulis saxicolus* (Cockerell). The difference between the two subspecies of *L. natalensis* is in the width of the sole as opposed to the hyponotum (wider in *L. n. natalensis* and narrower in *L. n. brauni*). The main difference between *L. natalensis* and *L. saxicolus* is that *L. natalensis* has one subdistal annular swelling on the verge (one of the most important diagnostic features of veronicellids) and *L. saxicolus* does not. It merely has a distal glans (Forcart, 1953).

Fig. 2a shows the penial complex of *L. haroldi* as it is seen through a dorsal incision after lifting the buccal mass up and to the left. The arrow on Fig. 2a shows the point at which the penial complex was lifted and flipped over to the left thus revealing the arrangement as shown in Fig. 2b. One can grasp the functional morphology easier in this view. The verge is housed in the sac and extends anteriorly through the genital opening during mating. Fig. 2c shows a dissected view of the verge in a contracted state inside of the penial sac. Fig. 2d shows the verge lifted from the sac.

Discussion: These new animals are unlike

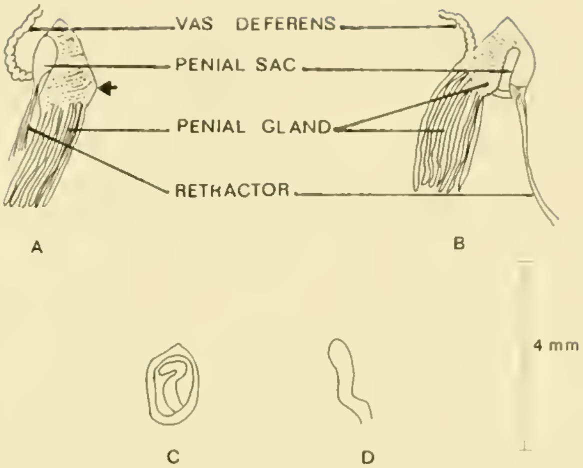

FIG. 2. *Reproductive structures.* **a.** *penial complex as seen in dorsal incision after lifting the buccal mass up and to the left.* **b.** *penial complex after lifting up and to the left at the point shown by an arrow in Fig 2a.* **c.** *dissected view of verge in penial sac.* **d.** *verge lifted from sac.*

either of the two species known from the Durban area. External appearance is totally different, L/W index in adults is much greater than in either of them, and this new species seems to be longer overall (although not enough specimens of any of the three species have been measured to validate that statement). Hyponotum-sole measurements are closer to those of *L. natalensis*. Dissection as shown in Fig. 2 reveals the reproductive anatomy to be closer to *L. natalensis* in that the verge appears essentially similar *except* it does not have the annular swelling.

I believe, therefore, that these specimens are members of a species heretofore unknown.

Type locality: The type locality of these slugs is a *Typha* marsh on Stamford Hill, Durban, Natal, South Africa. It is bounded by Walter Gilbert Road on the south, Unrgeni Road on the west, Athlone Drive on the north, and Snell Parade on the east. At the time of collection in December 1977 this was an empty lot which was used in part as a dump. The *Typha* marsh was on the north end. Recent correspondence (January 1979) from Mr. Lynn Raw indicated that the actual site where the slugs were found has now been bulldozed for a road. He further indicated that he has checked the type locality several times throughout the past year and has been unable to find any more slugs. The slugs were found about 1.5 m up on the *Typha* leaves and all appeared to be inactive. Air temperature was 30° C; wind was estimated at 25K.

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PISIDIUM FALLAX (BIVALVIA: PISIDIIDAE) IN THE SOUTHWESTERN OZARK PLATEAUS

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ABSTRACT

The freshwater fingernail clam, Pisidium fallax *Sterki, is reported for the first time from the Interior Highlands of Arkansas and Missouri.*

Pisidium fallax Sterki (1896) has recently been identified from several drainages of the southwestern Ozark Plateaus. These collections represent a new regional record for this species. With the exception of a record from Alabama (Herrington, 1962), it had not been reported south of the extent of maximum glaciation. West of the Mississippi River, it had not been collected south of Iowa (Herrington, 1962).

Numerous specimens have been recently collected from the basins of the Illinois and White rivers in Washington County, Arkansas, and the

Elk River in McDonald and Newton counties, Missouri and Benton County, Arkansas. Seven of these specimens from Little Sugar Creek, Bella Vista, Benton County (R30W, T20N, section 7), Arkansas, collected August 26, 1978, have been deposited in the University of Arkansas at Fayetteville Museum (UAFM no. 80-1-1), and nine specimens from Little Sugar Creek, Jane, McDonald County (R31W, T21N, section 10 and 15), Missouri, collected September 2, 1978, are in the University of Colorado Museum (UCM no. 29542). Previous records for *Pisidium* from the southwestern Ozarks include *P. abditum* (Haldeman, 1841), *P. friersoni* Sterki (1906), *P. neglectum* Sterki (1906), *P. noveboracense* (Prime, 1854) (all synonyms of *P. casertanum* (Poli, 1791)), *P. sargenti* Sterki (1901), (now *P. adamsi* Stimpson, 1851), *P. virginicum* Prime (1865) (now *P. dubium* (Say, 1816)), *P. punctatum* Sterki (1895), *P. fraudulentum* Sterki (1912), (now *P. compressum* Prime, 1852), and *P. compressum* (Sampson, 1894, 1913; Hinkley, 1916; synonymies from Burch, 1975).

The specimens collected from the drainages of the southwestern Ozark Plateaus have flattened beaks, some so flattened that incipient ridges are often present and specimens may be confused with *P. compressum.* Herrington (1962) also documented this similarity as well as similarities in shell outline between *P. fallax* and *P. casertanum.* These similarities may have caused some misidentifications in the past and additional study may be necessary to determine the actual occurrence and distribution of sphaeriids in the Interior Highlands. *Pisidium fallax* probably occurs in the downstream basins of the Illinois and Elk rivers in Oklahoma and may also be present in the Kansas portion of the Spring River drainage. This assumption is based on the similarities of the molluscan faunal assemblages found among streams on the western slope of the Ozark Plateaus. Considering the above observations and the Alabama record, this species may have a more extensive distribution than previously recognized.

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SASSIA LEWISI, A NEW CYMATIID GASTROPOD FROM THE CARIBBEAN SEA

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Recent exploratory work on the lower shelf faunas of the Caribbean region has uncovered large numbers of new and unusual gastropods. One of these new species represents the first record of the cymatiid genus *Sassia* Bellardi, 1872, in the Recent fauna of the Atlantic Ocean, and is described herein.

Sassia (Sassia) lewisi *new species*

Figs. 1 and 2

Description: Shell to 28 mm; spire angle 43°-46°; protoconch with 2 whorls, pitted, glassy; teleoconch with 6-7 rounded whorls; varices corded, sharply shouldered, repeating every 270°; shell cancellate, axial ribs more prominent than spiral cords; spiral sculpture of 7 cords on body whorl, and 4 or 5 cords on the siphonal canal, with 3-5 fine spiral threads between adjacent cords; 3 or 4 spiral cords visible on each of the preceding whorls; axial sculpture of 12-16 ribs; shell color golden-tan, with dark-brown blotches on and behind varices interrupted by a white spot at the

FIGS. 1-3. Sassia lewisi *new species.* **1**, *Holotype, ANSP 352235, dredged north of Contoy, Yucatan Peninsula, Mexico, in 60 to 80 meters (1.5×).* **2**, *Paratype, USNM 806061, trawled off St. James, Barbados, in 140 meters (1.5×).* **3**, Sassia semitorta *Kuroda and Habe, USNM 806062, off Tosa, Japan, in 100 meters (1.5×).*

shoulder of each varix, a white band around the 4th spiral cord and white areas at the base and tip of the siphonal canal; aperture roughly circular; outer lip with 6 strong denticles which form between spiral cords; inner lip appressed posteriorly, with 2 or 3 denticles posteriorly and 3 or 4 denticles anteriorly; siphonal canal open, moderate in length, slightly recurved.

Type material: Holotype—Academy of Natural Sciences of Philadelphia (ANSP 352235), length 27.9 mm; dredged north of Contoy, Yucatan Peninsula, Mexico (21°30′ N, 87°45′ W) in 60 to 80 meters. Paratypes—United States National Museum, Washington, D.C. (USNM 806061), lengths 26.8 mm, and 13.8 mm; dredged off St. James, Barbados in 140 meters.

Type locality: Off Contoy Island, Quintana Roo, Mexico, in 60-80 meters.

Range: Known from off the Yucatan Peninsula and Barbados.

Discussion: Sassia lewisi most closely resembles the Japonic *S. semitorta* (Kuroda and Habe, 1952) (Kuroda, Habe and Oyama, 1971: 128-129, pl. 28, fig. 1), from which it may be distinguished by its smaller overall size, smaller, less inflated protoconch, and finer, more regular sculpture. *Sassia semitorta* differs further by having a more lenticular aperture, mottled base coloration, and brown bands on the spiral cords.

This new taxon honors Hal Lewis, of the Academy of Natural Sciences of Philadelphia, in recognition of his contributions to the systematics of the Cymatiidae.

We thank Dr. Finn Sander, Bellairs Marine Laboratory of McGill University, St. James, Barbados, for providing the paratypes.

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DRILLING PREDATION IN A POPULATION OF THE EDIBLE BIVALVE *ANADARA GRANOSA* (ARCIDAE)

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ABSTRACT

Drilling by the muricid Bedeva blosvillei *(Deshayes) accounts for 88% of the mortality of the arcid bivalve* Anadara granosa *(L.) at Dodinga Bay, Halmahera, Indonesia. The high incidence is associated with a large number of incomplete drill-holes (.32 per individual). Right valves are attacked significantly more often than left valves. There is no difference in placement of complete and incomplete holes on the valves.*

As part of a survey of the shell architecture and causes of death of shelled marine molluscs in the tropical Indo-West-Pacific region, a collection of living molluscs and empty shells was made on 14 July, 1979, at Dodinga Bay on the west coast of Halmahera Island, Maluku, Indonesia (0° 50 min N, 127° 37 min E). The area is an extensive shallow-water mud-flat with stands of the grass, *Enhalus acoroides*, wide expanses of silt and sandy mud, and shoreward mangroves. One of the commonest molluscs in the very rich assemblage at Dodinga Bay was the edible arcid bivalve *Anadara (Tegillarca) granosa* (L.). A large number of empty valves of this species appeared to have been drilled by gastropods.

In order to draw attention to several unusual features about these drilled valves, I shall consider the following three questions in this note. (1) What proportion of the population of *A. granosa* at Dodinga Bay was killed by drilling predators? (2) Is there a difference in placement of complete and incomplete drill-holes on the valves? (3) How widespread is drilling predation in other populations of *A. granosa*?

A total of 27 right valves and 25 left valves, ranging in length from 24.2 to 55.1 mm, was collected at Dodinga Bay; most were still hinged together, and many were found in life position. Two individuals were drilled through the hinge-line between the valves. In the remaining 48 valves, complete drill-holes were found in 6 of 23 left valves (26%) and in 15 of 25 right valves (60%). Because no individual with more than one complete drill-hole was found, the mortality attributable to drilling predation is thus 2x(2+6+15)/52, or 88%.

In addition to empty valves, 21 living individuals, ranging in length from 18.7 to 48.3 mm, were collected at Dodinga Bay. A total of 16 incomplete drill-holes was encountered on the valves of living and dead individuals (Table 1); the number of incomplete drill-holes per individual is thus 16/47, or .32. Two individuals (an empty right valve 55.1 mm long, and the right valve of a living clam 30.5 mm long) had two incomplete drill-holes each. As Table 1 shows, the frequency of unsuccessful drilling generally increases in the larger size classes.

When the number of complete and incomplete drill-holes is summed for right and left valves, it is seen that right valves are attacked about twice as often (25 holes in 48 valves) as are left valves

TABLE 1. *The occurrence of incomplete drill-holes in relation to shell length in* Anadara granosa *from Dodinga Bay. N = number of valves of living and dead individuals.*

Size class (mm)	Incomplete holes per individual	N
15 to 19	0	4
20 to 24	0	5
25 to 29	.14	14
30 to 34	.26	15
35 to 39	.33	12
40 to 44	.33	18
45 to 49	.44	18
50 to 55	1.00	4

(12 holes in 46 valves); this difference is significant at the 0.05 level (chi-square test). No significant difference between right and left valves is evident when complete and incomplete holes are treated separately.

Of a total of 37 complete and incomplete drill-holes made through either the right or the left valve (thus excluding the two made through the hinge-line), 32 (86%) are confined to the smoothly ribbed posterodorsal portion of the valve; only 5 drill-holes (of which 2 are incomplete, both on left valves), were found on the sector of the valve where the radial ribs are tuberculated (about 90% of the valve surface). All holes were made between the ribs. The proportion of unsuccessful holes made in the tuberculated portion of the shell (12.5%) is nearly identical to that of successful holes (14%). There is no obvious difference in the placement of complete and incomplete drill-holes.

The agent of drilling appears to be the muricid gastropod *Bedeva blosvillei* (Deshayes), an unusually high-spired species with a distinct anal notch and a slender open siphonal canal. Several individuals of this species (2 of 10 collected) were found to be drilling *A. granosa* at Dodinga Bay; in the laboratory, *Bedeva* avidly drilled several tellinid and venerid bivalves. All the drill-holes in *A. granosa* were of the typical muricid type described by Carriker and Yochelson (1968). No other mollusc collected at Dodinga Bay showed signs of drilling by *Bedeva*; the few drill-holes that were found in *Cerithium coralium* Kiener and *Nassarius* spp. are attributable to naticids. No other soft-bottom muricids were seen at Dodinga Bay.

The localization of drill-holes in the posterodorsal portion of the shell is presumably the consequence of the essentially epifaunal habit of *Bedeva* and of the shallowly infaunal mode of life of *A. granosa*. Unlike most naticids, *Bedeva* (maximum length 40 mm) is relatively small compared to its prey, and has a small foot that is incapable of enveloping the clam. The only portion of the prey available for drilling is thus the relatively exposed posterodorsal region. I do not know why the right valve is attacked more frequently than the left.

Three small samples of *A. granosa* in the U. S. National Museum (Washington, D. C.) were examined for signs of drilling. No complete or incomplete drill-holes were found in 18 individuals from Haigo, Japan; 10 individuals from near Cebu, Philippines; or 10 individuals from Singapore. Although *B. blosvillei* is distributed from Japan to northeast Australia (Radwin and d'Attilio, 1976), it may be only locally abundant and effective as a predator.

Several authors have commented that, whereas incomplete naticid drill-holes are rarely met with, unsuccessful predation by drilling muricids is often observed (Taylor, 1970; Adegoke and Tevesz, 1974; Kojumdjieva, 1974; see Vermeij *et al.*, in preparation, for examples of unsuccessful naticid predation). It is curious that the very high incidence of unsuccessful predation by *Bedeva* on *A. granosa* at Dodinga Bay is associated with an extraordinarily high proportion of individuals that were killed by drilling (88%). In no other population of Recent or fossil tropical or subtropical bivalves is the importance of drilling as a cause of death so great (Vermeij, 1980). The highest previously recorded value of drilling was 84% for *Periploma margaritacea* (Lamarck) from Texas (calculated from Rosewater, 1980). Although the importance of drilling varies greatly from population to population (Vermeij, 1980), drilling is a form of predation to be reckoned with in attempts to culture such edible clams as *Anadara granosa*.

ACKNOWLEDGMENTS

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A NOTE ON ENCAPSULATION OF DETRITAL GRAINS WITHIN THE SKELETONS OF FOSSIL MOLLUSKS

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The microscopic examination of bivalves, gastropods, and scaphopods reveals that certain morphologic elements of fossil skeletons have acted as traps that either become packed with mud or plugged with larger, sand-sized grains that are nearly the same size as the traps. For purposes of description and emphasis we distinguish between simple *in-filling,* or the partial to complete stuffing of the vacant interior space of a shell (forming steinkernen), and *encapsulation,* or the physical lodging of sand grains within cavities either between skeletal walls or behind a rigid skeletal element (compare Figs 1 and 2). The purpose of our note is to describe the taphonomic phenomenon of encapsulation, and to outline the paleoecologic and sedimentologic significance of this pre-diagenetic feature of sandy, fossiliferous Cenozoic deposits.

We have observed examples of encapsulation in sandy deposits from a wide range of depositional environments, from backbarrier lagoon to abyssal plain. Examples of encapsulation are shown in Figs. 2 through 6. Skeletons probably encapsulate detrital grains in any environment where grains and empty shells are mixed together by current and wave action, and where grains and skeletons frequently collide resulting in the jamming of mobile particles into skeletal cavities. The skeletal traps most often observed in our samples included: 1) gastropod apertures, 2) broken apices and punctured whorls of gastropods, 3) siphonal canals of gastropods, 4) cardinal and lateral sockets of bivalves, 5) pits or troughs between plicate, costate, or reticulate exterior surface ornamentation of bivalves, and 6) scaphopod apertures. We also have observed encapsulated grains in: 1) zooecial openings in bryozoan zoaria, 2) openings in broken tubiferous side plates of balanids, 3) interseptal areas in scleractinian corallites, and 4) borings in various types of calcified skeletons (e.g., Figs. 5 and 6). Sand-sized grains of quartz, garnet, opaque heavy minerals, and skeletal fragments are involved typically in encapsulation.

Perhaps the most important aspect of encapsulation is that the physical and hydrodynamic properties of skeletons are altered considerably by addition of weight during the encapsulation event. Shells with encapsulated grains are heavier than other shells of similar size, and are less likely to be rolled about by currents and waves. Thus, encapsulation probably increases the preservation potential of mollusk shells. When shell openings are plugged with a detrital grain, the weight of the shell increases substantially and the likelihood of transport into a foreign depositional environment diminishes significantly. Therefore, fossil mollusk shells, especially smaller specimens, with encapsulated grains are likely to have been entombed near the area in which the original mollusk lived.

The properties of the encapsulated detrital grains and the entombing sediment layer in general also are affected by encapsulation. We have observed encapsulated grains in skeletons from turbidite deposits and submarine canyon

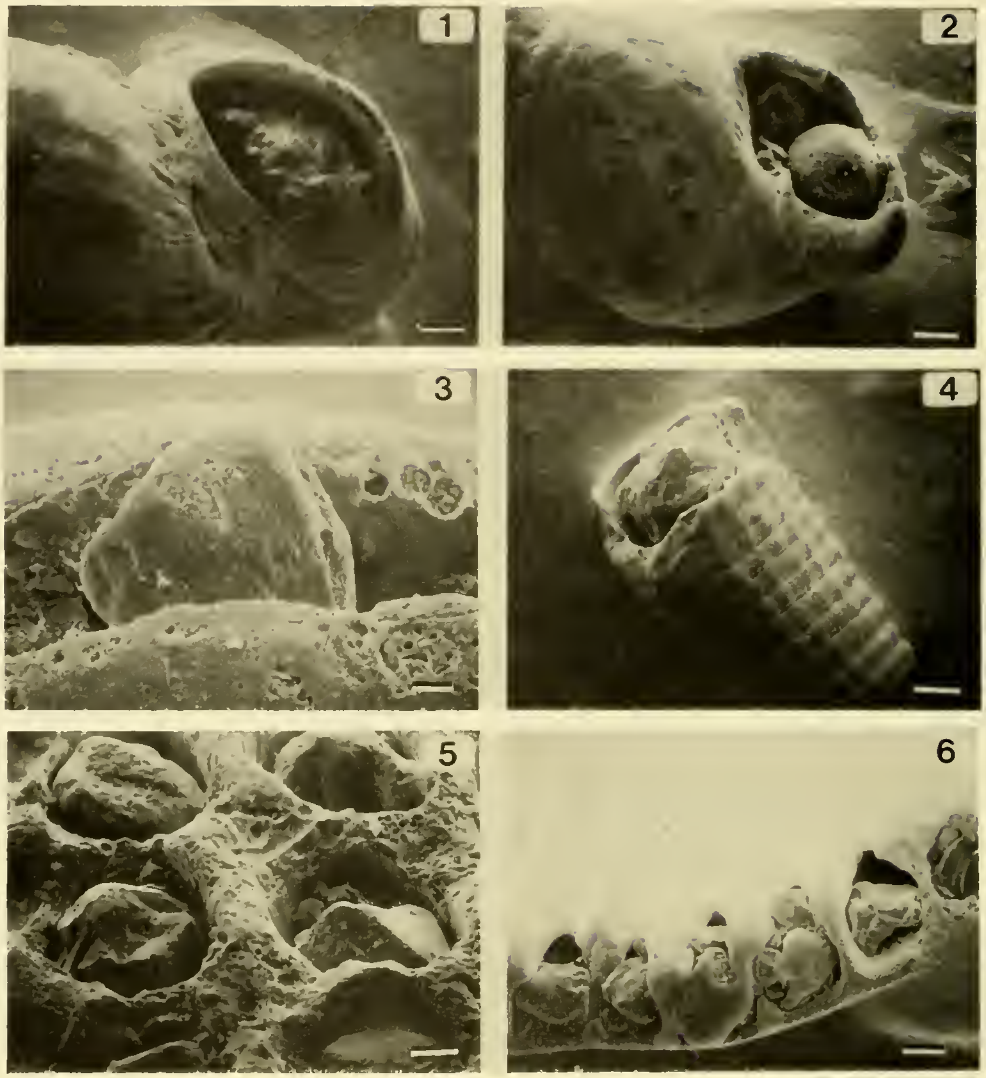

FIG. 1-6. 1, *Scanning electron micrograph of aperture of* Truncatella pulchella *Pfeiffer showing carbonate mud in-filling. Specimen from Holocene deposits, Crane Key, Florida Bay, U.S.A. (Scale bar represents 200 μ)* 2, *Scanning electron micrograph of aperture of* Odostomia impressa *(Say) showing well-rounded quartz grain encapsulated between columellar fold and shell wall. Specimen from late Pleistocene backbarrier deposits, Dare County, North Carolina, U.S.A. (Scale bar represents 200 μ)* 3, *Scanning electron micrograph of opaque heavy mineral grain encapsulated within lateral socket of* Mulinia lateralis *(Say). Specimen from late Pleistocene inner shelf deposits, Dare County, North Carolina, U.S.A. (Scale bar represents 25 μ)* 4, *Scanning electron micrograph of broken* Caecum insularum *D. R. Moore with encapsulated quartz grain. Specimen from Holocene channel deposits within La Plata Submarine Canyon, Puerto Rico. (Scale bar represents 100 μ)* 5, *Scanning electron micrograph of* Discoporella *sp. showing zooecial openings plugged with encapsulated quartz, garnet, and opaque heavy mineral grains. Specimen from late Pleistocene inner shelf deposits, Dare County, North Carolina, U.S.A (Scale bar represents 50 μ)* 6, *Scanning electron micrograph of side plate of* Balanus *sp. showing basal edge with encapsulated quartz grains. Specimen from late Pleistocene turbidite deposits, Hatteras Abyssal Plain off southeastern U.S.A. (Scale bar represents 200 μ)*

channel deposits (Figs. 4 and 6). If the grains were trapped prior to transport, they may have a potential utility in the identification of the source areas of density flow deposits. The longevities of unstable detrital minerals, such as hornblende, may be slightly prolonged by encapsulation; fragile fossils are protected from fragmentation during entombment by encapsulation

within more durable skeletons. Because a decrease in interstitial volume accompanies encapsulation within shells, cementation may proceed faster between calcified mollusk skeletons and encapsulated grains than in the surrounding sediment giving rise to irregular patterns of Lithisication and induration within the resultant rock (see Taylor and Illing, 1969, p. 79-80). Skeletons with encapsulated grains occur typically in sediment samples that are used in grain size analyses, and the effects of dissolving the carbonate fraction and liberation of the insoluble grains during sample preparation has a previously unassessed impact on the measured textural parameters of the sediments, such as mean grain size (Pilkey, 1964). This aspect of encapsulation needs more study.

The importance of encapsulation in anchoring shells in place, in preventing prolonged episodes of hydraulic reworking of shells before final entombment, and in modifying the lithologic properties of sedimentary rocks are all unexploited areas of research in taphonomy and physical sedimentology. Our illustrations and descriptions of the encapsulation of detrital grains within the skeletons of fossil mollusks, and our brief account of the significance of encapsulated grains, are intended to focus attention on this interesting, unstudied characteristic of sediments comprised of sand and shells.

ACKNOWLEDGMENTS

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BOOK REVIEW

Hawaiian Marine Shells by E. Alison Kay. 1979. 654 pp., 195 figs. (33 in color). Section 4, Mollusca, Reef and Shore Fauna of Hawaii. Bishop Museum Press, Honolulu, HI 96816. $30.00.

This is one of the better faunal treatments of marine mollusks to have appeared in recent years, and certainly will adequately serve both professional marine zoologists and amateur malacologists interested in Hawaiian mollusks. Most of the estimated 1,000 species of marine mollusks of the Hawaiian Chain are well-illustrated, described in detail, their habitat and relative abundance noted, and their overall distributions recorded. The taxonomy is well-done, with both author and date given with each taxon.

The introduction does justice to the general geography and marine zoology of Hawaii, the types of marine habitats, fossil history, endemism, larval forms, economic aspects, and the history of malacology from Captain Cook's first visit to the modern activities of the Bishop Museum and Hawaiian Malacological Society. This well-bound book has an excellent bibliography and index, and it certainly is reasonably priced for a book of this size and excellent nature. If any criticism were to be leveled, it is at the unwise and unfair practice of publishing quite a few new species in a semi-popular, expensive book. The book was in preparation for years and there certainly must have been an opportunity to have described new species in more normal, scientific channels. Stanford University Press was resoundingly censured when they published "Sea Shells of Tropical West America" in 1971, with thirteen new species. Research workers are obliged to obtain a copy of a large book when it has new taxa. This practice sells more copies of a layman's book, and evidently is one that non-profit university or museum presses cannot resist.

—R. Tucker Abbott,
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Dr. David S. Brown is a senior scientist on the staff of the Medical Research Council of Great Britain and has been based for 20 years at the British Museum (Natural History) working with a team on research into host/parasite relations. During long periods of field-work in Africa, he has studied the entire gastropod fauna of fresh and brackish waters over large areas of the continent.

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CONTENTS

FIG. 1. *Morris K. Jacobson at a shell club gathering (1979).*

FIG. 2. *Karl collecting in Cuba in 1955.*

MORRIS KARL JACOBSON (1906–1980)

Although a scholar in linguistics and an educator by profession, Karl Jacobson became a leading participant in American malacology. His sudden death from a heart attack, at age 73, on July 21, 1980, was a personal loss to his many friends and to our field. Known for his unbounded energy and good humor, Karl made many scientific contributions to malacology and wrote nine popular books on mollusks and other invertebrates, some in collaboration with William K. Emerson and David R. Franz.

Born December 29, 1906, in Memel, East Prussia (now Lithuania), he came with his family to America at the age of one. He was educated in New York, and received his B.S. and Masters degrees from Columbia University. He taught foreign languages in Queens, New York, High Schools until his retirement in 1969. He could speak Spanish and German fluently, and in recent years mastered the translation of Russian malacological literature.

He championed the malacological education of the layman, founded the New York Shell Club in 1949, and was elected President of the American Malacological Union in 1954. He was officially connected with two museums specializing in mollusks, the American Museum of Natural History in New York City, and the Museum of Comparative Zoology at Harvard. Although primarily interested in land mollusks, he delved into marine and freshwater forms as well. His field trips, taken during school vacations, included several to Cuba from 1946–1955, Nicaragua, 1964, Jamaica, 1949, and northern Canada, 1968. He wrote over 65 scientific papers, including several for *The Nautilus,* and produced nine popular works, the best known being co-authored with William K. Emerson on the marine and non-marine mollusks of the east coast of the United States.

Karl became a resident of Palm Bay, on the east coast of Florida, upon his retirement. He is survived by his wife, Lena Schechter Jacobson, a son and two grandchildren. By hapchance, a few days before he died, he was made an honorary life member of both the American Malacological Union and the Astronaut Trail Shell Club in Melbourne. Further bibliographical data are available in *American Malacologists,* p. 316, and the New York Shell Club Notes, no. 264, Sept. and no. 265, Oct. 1980. – R. Tucker Abbott, Melbourne, Florida.

FIG. 3. *A formal portrait of Morris Karl Jacobson (1976).*

THE INFLUENCE OF THERMAL DISCHARGES AND SUBSTRATE COMPOSITION ON THE POPULATION STRUCTURE AND DISTRIBUTION OF THE ASIATIC CLAM, *CORBICULA FLUMINEA*, IN THE NEW RIVER, VIRGINIA*

Robert L. Graney[1], **Donald S. Cherry**[1], **John H. Rodgers, Jr.**[2], and **John Cairns, Jr.**[1]

ABSTRACT

By the summer of 1977, the Asiatic clam, Corbicula fluminea, *was successfully established in the confines of the thermal effluent of the Glen Lyn Power Plant, located along the New River in southwestern Virginia. Numbers were either greatly reduced or eliminated outside the thermal influence during severe winter conditions (lowest water temperature was 0°C for about a two-week period) in 1976 but inhibited to a lesser extent in winters of 1977–1978 (minimum temperatures of about 3–4°C). Clam density and sediment composition, sampled from six stations established above, below, and within the thermal discharge, indicated that* Corbicula *numbers within and outside the effluent are generally independent of sediment composition. In the sediment (clay, silt, sand, pebble, cobble) from heated versus unheated stations, pebble constituted the greatest amount (59.0 versus 71.8%, respectively) followed by sand (32.7 and 23.7%). Heated water appeared to be most influential on clam survivorship and size distribution. Peak densities reached about 11,522/m² (station 4) in the thermal discharge in February, 1978 while highest densities in unheated areas (station 1) reached about 2,286/m² in November, 1978. The diversification of size classes (shell length <7.5, 7.5–13.5, 13.6–18.5, 18.6–28.0, >28.0 mm) was higher in heated stations with more uniform distribution occurring in summer to fall of 1978. Small clam sizes (<7.5, 7.5–13.5 mm) were consistently greater in February and November in the thermally influenced stations and only during September and November in unheated areas. The ecological impact of these density changes and subsequent migration tendencies are discussed.*

INTRODUCTION

Since its introduction to the Pacific coast of the United States in 1938 (Sinclair, 1971), the Asiatic clam, *Corbicula fluminea* (Müller), has methodically invaded many river systems in the Mississippi and Ohio River drainage basins. The organism has become widely established in the southern and western states but appears less successful in the colonization of colder, northern states. The potential as a biological pest to a variety of industries (power generating, agricultural, sand and gravel industries) has been well documented (Ingram, 1959; Sinclair, 1964; Prokopovich, 1965; Goss and Cain, 1977). The development of effective control procedures may be enhanced by the elucidation of factors that influence population dynamics and dispersal mechanisms. After its appearance in the New River within the thermally enriched confines of the Glen Lyn Power Plant in 1975 (Rodgers et al., 1977), population maintenance has been augmented by the elevated tempera-

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tures with further upstream migration being inhibited by unusually severe winter conditions (water temperature of about 0°C).

Unlike the freshwater unionid mussels, *Corbicula* possess no glochidial larval stage (Sinclair, 1963), with its natural dispersal being restricted to a nonswimming planktotrophic veliger. This restriction has prompted several theories which were largely based on anthropogenic dispersal mechanisms. Convincing evidence supporting any of these theories is absent, although Thompson and Sparks (1977) did not find evidence to support the hypothesis that clams may be dispersed through guts of waterfowl. Other suggested mechanisms include 1) transfer of clams in river gravel located on barges; 2) dispersal in bait buckets or by aquarium enthusiasts; and 3) transfer of larvae in the bilge waters of ships. Although the mechanism of dispersal is unknown, factors which may influence habitat preference and geographic distribution are better understood. The potential tolerance to stressed ecosystems (Burress and Chandler, 1976), reproductive capacity, and precocious development has enabled the Asiatic clams to exploit a wide variety of habitats. Successful colonization of cobble, pebble, sand, silt and mud substrates has been reported for both lentic and lotic habitats (Sinclair, 1953; Ingram, 1959; Rinne, 1974; Sickel, 1974; Aldridge, 1976). An apparent lack of preference in colonization by *Corbicula,* along with a rapid growth and reproductive development, may have important ecological implications. Other abiotic factors (e.g., water quality, temperature), which may influence geographic distribution, have not been fully investigated. Both potassium and water hardness have been documented as possible limiting factors in the distribution of other molluscs (Hunter, 1964; Imlay, 1973), but such influence on the distribution of *Corbicula* is unknown. Temperature, however, appears to be a major influential factor in the geographic distribution of *Corbicula.* Laboratory determined upper and lower thermal tolerances of the Asiatic clam have been reported (Mattice and Dye, 1976), although extrapolation of these values to field conditions is difficult (i.e., interstitial water temperatures may differ from ambient temperature [Martens and Berner, 1977]). The objectives of this study were to evaluate the influence of thermally enriched waste water from power production and substrate composition upon the distribution and population structure of the Asiatic clam in the New River.

MATERIALS AND METHODS

Asiatic clams and substrate were collected from the New River (mean depth approximately 1.2 m, average width of 500 m) in the vicinity of a coal-fired generating plant (APCo-AEP) located at Glen Lyn, Giles County, Virginia (River Mile 95). Water is withdrawn from the New River for condenser cooling, and maximal plant cooling flow rates of 535 cfs can represent up to 45% of the total river flow during low flow periods. The hot water discharge is initially split and released into two areas (Fig. 1). Approximately half of the water is returned to the river just downstream from the intake and the rest is released into a dredged canal that passes into the East River.

Six sampling stations were established above, below and within the thermal effluent of the Glen Lyn plant (Fig. 1). Stations 1 and 2 in the New River, which were uninfluenced by heated water, were respectively located 140 and 45 m above the water intake facility situated adjacent to the power plant. Stations 3 and 4, which were

FIG. 1. *Location of the six sampling stations in the New River located above, within, and below the thermal effluent of the Glen Lyn Plant from October, 1976 to November, 1978.*

thermally influenced, were located approximately 50 m below the discharge pipe in the New River and 200 m from a dredged canal at the confluence of the East River, respectively. Station 5 was found approximately 260 m above Station 4 in the East River and received no heated discharge. The final site (Station 6) was established ~2,450 m downstream from the plant in the New River where elevated temperatures from waste heat were reduced by ~50%. River water, after passing through the plant, was heated to a maximum of 8°C (Station 3) above ambient temperature (Stations 1 and 2) in the New River with the ΔT being even higher in the East River between ambient (Station 5) and thermal conditions (Station 4).

Weather permitting, clams and sediment were collected monthly to bimonthly (October, 1976 through December, 1978) with five samples being collected at each station using a 0.25 m^2 quadrat with a plankton net attachment (mesh size = 1.0 mm). The large mesh size of the plankton net allowed passage of a large percentage of the larval stage clams. The substrate was shoveled to a depth of ~15 cm with clams and river sediment carried directly into the net by river current. Samples were returned within two hours to the laboratory for size class partitioning and density determinations. Clam size classes and sediment from each station were partitioned using a Rotop Testing Sieve Shaker (Tyler Industrial Products, Mentor, Ohio). Based on Gardner et al. (1976), clams were separated into five general classes: <7.5 mm (2.0 mm sieve), 7.5–13.5 mm (4.75 mm sieve), 13.6–18.5 mm (9.5 mm sieve), 18.6–28.0 mm (12.5 mm sieve), >28.0 mm (19.0 mm sieve). Sediment samples were separated (#10 sieve) into pebbles (2–64 mm) and cobble (64–256 mm) components. The smaller fractions, sand (0.02–2.0 mm), silt (0.002–0.02 mm), and clay (<0.002 mm), were partitioned according to the hydrometer method (Bouyoucos, 1962). In this procedure, soil characteristics were obtained by mechanical dispersion and hydrometer readout after the sedimentation process. To provide supportive information, monthly water samples were taken for analysis at the six sampling stations described earlier.

RESULTS AND DISCUSSION

The effects of thermal discharges on the Asiatic clam were twofold: 1) an alteration in the dynamics of clam populations residing in the thermal effluent, and 2) increased survivorship of clam populations during colder weather. Peak densities of clams within the effluent (8°C > ambient temperature) were considerably higher than those from ambient stations of the New River (Figs. 2 and 3). Densities in the thermally influenced East River (Station 4) were approximately 1,020/m^2 in September, 1977 and increased to 11,522/m^2 by February, 1978. In the uninfluenced area of the New River (Station 1), densities were 94/m^2 in February, 1978 and had increased to 2,286/m^2 by November of the same year. In comparison (Fig. 2), peak densities in the thermal discharge occurred between January and February, 1978, with highest densities

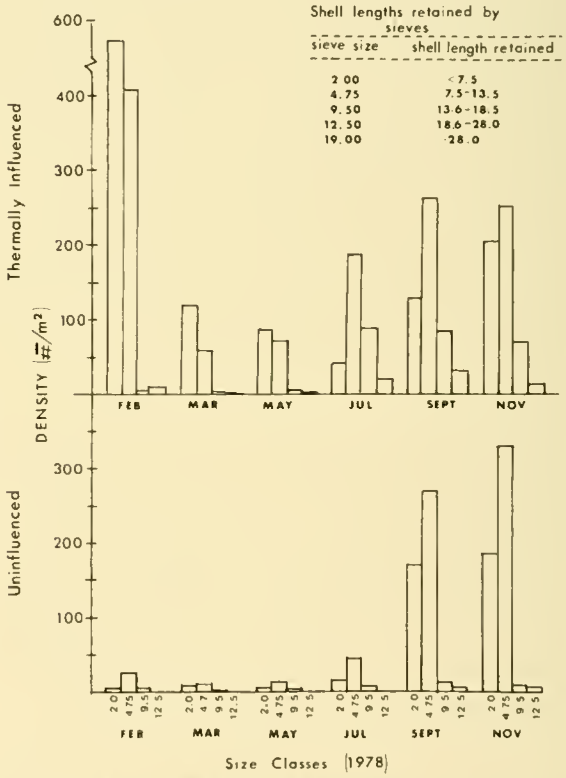

FIG. 2. *Clam densities partitioned into several shell lengths (< 7.5 to 28.0 mm) by sieve sizes 2.0 to 19.0 mm in thermally influenced and unheated regions of the New River. Data are presented as the overall mean between thermal and unheated stations from February through November, 1978.*

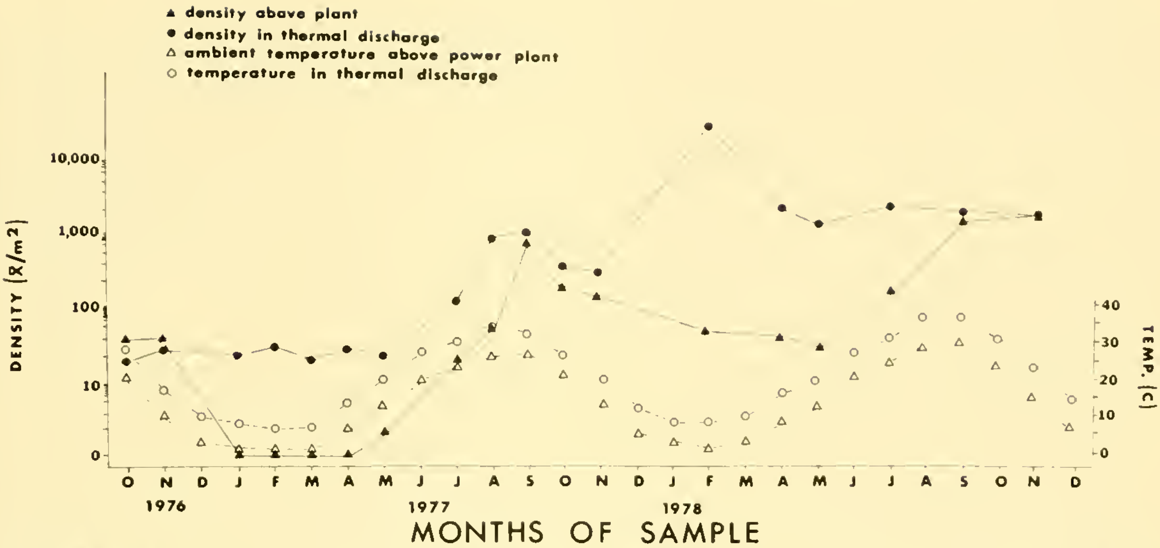

FIG. 3. *Maximum density of* Corbicula *clams sampled and water temperature in ambient (Station 1) and thermally influenced (Station 4) locations of the New River from October, 1976 through December, 1978.*

in the New River occurring in late fall of the same year.

Sediment characteristics of the six stations in which the Asiatic clam was sampled included clay, silt, sand, pebble and cobble with pebble being predominant followed by sand (Table 1). Pebble was higher in unheated stations ($\bar{X}$ = 71.8%) than in thermally influenced ones ($\bar{X}$ = 59.0%), with sand forming a greater percentage in heated stations ($\bar{X}$ = 32.7%) than in uninfluenced ones ($\bar{X}$ = 23.7%). On a seasonal basis, trends in sediment composition were difficult to evaluate. Substantial seasonal shifts in the percent composition were observed, with the major changes occurring between the sand and pebble fractions. These shifts were greatest in the spring, most likely resulting from the increased flow caused by runoff from snow thaw. However, due to compounding variables, it was not possible to determine whether these shifts in substrate composition had any impact on clam survival or distribution.

From the literature (Aldridge, 1976; Gardner et al., 1976), the age of clams retained by the 2 mm sieve (clams < 7.5 mm) was estimated to be about 4–6 months. In the influenced and uninfluenced stations, clams in the < 7.5 mm size class first showed a substantial increase by September, 1978, although the density of small clams in the heated region was first highest in February of that year (Fig. 2). This corresponded fairly well with the beginning of the spawning season, which generally occurred in this area between April and May. During winter, a major portion of the effluent clam population also consisted of the 7.5 mm size class, while in the unheated areas of the New River, few clams of this size class were found. The predominant composition of clam sizes was < 7.5 and 7.5–13.5 mm especially in September-November of 1978 in all stations and also earlier in February in the thermally influenced stations. Two possible explanations for the difference in age structure observed in the heated and unheated areas of the river were plausible. First, the colder temperatures at

	Percent Sediment Composition				
Station	Clay	Silt	Sand	Pebble	Cobble
3	2.2	1.1	36.7	51.2	8.8
4	1.8	0.8	37.4	55.0	5.0
6	1.7	0.6	24.0	70.6	3.1
x	1.9	0.8	32.7	59.0	5.6
1	1.5	0.9	28.6	63.8	5.2
2	1.3	0.5	23.3	73.3	1.6
4	1.1	0.6	19.2	78.2	0.9
$\bar{x}$	1.3	0.7	23.7	71.8	2.5

TABLE 1. *Percent composition by weight of sediment samples for 1978 in thermally influenced (3, 4, and 6) and unheated (1, 2, and 5) stations in the New River.*

the ambient stations of the New River may have enhanced mortality among the younger clams and also contributed to the simultaneous reduction in the density of older clams. Secondly, the occurrence of immature clams through May of 1978 may have resulted from a longer spawning season for clams residing in the thermal effluent. Elevated temperature may have extended the spawning season further into the winter. Confirmation of this thermal effect will require a continued comprehensive study of *Corbicula* population dynamics.

The maintenance of clam populations in heated discharges during winter periods may enable the organism to extend its northern distribution. The extremely cold winter of 1977 virtually eliminated the Asiatic clam from the unheated sampling stations in the New River (Fig. 3). This effect was not as evident in the milder winter of 1978, although a reduction in clam densities was observed. In the uninfluenced stations, the seasonal temperature cycles generally corresponded with clam population fluctuations, especially during the 1976–1977 winter season. This trend agreed with other authors (Horning and Keup, 1964) who reported a major population decline following severe winter conditions.

By examining the initial western to southern distribution of *Corbicula* throughout the United States (Sinclair, 1971; Fuller et al., 1973; Echblad, 1975), it appears that temperature may be a primary limiting factor restricting extensive northern migration. Mattice and Dye (1975) reported a lower ultimate incipient lethal temperature of about 2°C for *Corbicula*. This may have important implications concerning the ultimate northern distribution of the Asiatic clam. These power plant thermal effluents may provide protective habitats in the "temperature controlled" northern distribution. Clams inhabiting the thermal discharge may survive extremely cold northern winters, thus providing a source of propagules for further northern migration during the warmer months. By 1975, the northern migration of *Corbicula* had extended to Lansing, Iowa, where the clam occupied the thermal discharge of a generating power plant (Echblad, 1975). Generally, each thermally influenced area of a river may serve as a "stepping stone" to facilitate further northern expansion and establishment.

Biofouling of condenser pipes is another area of concern in areas where thermal effluents may promote clam maintenance followed by rapid density increases. The heated discharge will 1) eliminate the colder ambient water temperature as a controlling factor and 2) increase the density of clams present in the effluent, thus increasing the probability of fouling. Both factors may add to the difficulty in developing effective control procedures.

In summary, the influence of substrate composition and heated waste water discharge on the population dynamics and distribution of the Asiatic clam was investigated and found to be independent of sediment substrate composition. No relationship was found between clam seasonal density cycles and possible seasonal shifts in substrate composition. The thermal discharge from the power plant, however, exerted a definite influence upon clam population dynamics and distribution. A substantial increase in clam density occurred in the heated effluent which may facilitate further expansion of northern riverine habitats and augment biofouling problems associated with steam generating power plants.

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CELLULASE ACTIVITY IN THE FRESHWATER GASTROPOD *AMNICOLA LIMOSA*

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ABSTRACT

Cellulase activity was measured in whole animal homogenates of the prosobranch gastropod Amnicola limosa *(Say). A modified viscometric assay yielded an activity of 500 Hultin Units · mg protein*$^{-1}$*. A reducing sugar assay yielded an activity of 13.6 μg glucose · min*$^{-1}$ *· mg protein*$^{-1}$*. Highest activities were observed at the two lowest pH values tested, pH 5.6 & 6.6 for both assay techniques.*

The freshwater gastropod *Amnicola limosa* (Say) can quantitatively and qualitatively influence epilithic periphyton communities (Kesler, 1979, 1980). Removal of ingested material was assumed (Calow, 1975). Some of the ingested algal species possess cellulose cell walls which may decrease their value to grazers. In order for *A. limosa* to completely digest the cell walls, and thereby increase assimilation efficiency, these snails would require cellulase enzymes. The origin of these enzymes is immaterial, being either bacterial or endogenous (Parnas, 1961). Calow and Calow (1975) demonstrated a significant correlation between snail cellulase activity and the ability of various species to digest the alga *Scenedesmus* which has a thick cellulose cell wall.

The present study was undertaken to determine *A. limosa* cellulase activity and to compare this activity with cellulase activities published for other species. Possession of high cellulase activity by *A. limosa* would support the assumption that ingested cellulose-containing cells were at least partially assimilated, and that these cells compose part of *A. limosa's* natural diet.

METHODS

Amnicola limosa specimens were collected

from Nonquit Pond, Rhode Island, a soft water, highly stained lake. The snails were kept without food at 18–20°C for at least 24 hours before use. Whole animals were homogenized because *A. limosa's* small size (2–3 mm high) made dissection of the crystalline styles impractical. Homogenization was performed with a mortar and pestle in ice. The homogenate was centrifuged for 30 minutes at 10,000 g's and 3°C. The supernatant was used as the enzyme source.

Cellulase activity was determined by a modified viscometric procedure of Parnas (1961) and by the reducing sugar assay of Bernfeld (1951). A modified Cannon-Fenske viscometer (Fisher, 1959) was used in the viscometric assay, maintained at 29°C. Medium viscosity carboxymethylcellulose (CMC) was obtained from Sigma Chemical Company. The reaction mixture consisted of 2 ml phosphate buffer and 5 ml 1% CMC solution. A rubber tube attached to the receiving arm of the viscometer allowed the mixture to be returned to its original level by blowing. After the initial rate of flow was determined, 0.1 ml of enzyme was added to the reaction mixture and the flow rate determined.

The reducing sugar assay determined cellulase activity by estimating the amount of glucose liberated from CMC. The reaction mixture consisted of 5 ml 1% CMC solution, 4.5 ml 0.2M phosphate buffer (of varying pH) and 0.5 ml of enzyme extract, maintained at 29°C. Upon addition of the enzyme to the reaction mixture (time 0) and at 2 minute intervals thereafter, 1 ml of the reaction mixture was added to 1 ml of dinitrosalicylic acid solution, stopping the reaction. Absorbances of these samples were determined at 540 nm.

The total protein content of the whole animal homogenate was determined using the method of Lowry et al. (1951). Bovine serum albumin was used as the protein standard.

RESULTS

Cellulase activity was observed using both techniques. The highest cellulase activities, using the viscometric technique, were observed at the two lowest pH values tested, pH 5.6 and 6.6. The cellulase activity at pH 5.6 was approximately 500 Hultin Units (H.U.) · mg protein^{-1} (Hultin and Wanntorp, 1966).

Results of the reducing sugar assay also indicated cellulase activity. Maximum activity was 13.6 μg glucose · min^{-1} · mg protein^{-1} at pH 5.6.

The total protein content of the whole animal homogenate was 2.45 ± 0.44 (1 standard deviation) mg protein · ml^{-1}. This was equivalent to 0.114 g protein · g snail^{-1}, or 11.4% by wet weight.

DISCUSSION

Our value of 500 H.U. · mg protein^{-1}, determined by the viscometric technique, was lower than four of the five values reported by Elyakova (1972) for marine gastropods. Our data, however, were obtained using whole animals, while Elyakova measured cellulase activity of isolated hepatopancreas tissue.

A. limosa's maximum cellulase activity at pH 5.6 was consistent with observations made by Parnas (1961) on hepatopancreas cellulolytic activity in the pulmonate *Levantina hierosolyma*.

Our cellulase activity value, determined from the reducing sugar method, was similar to freshwater prosobranch cellulase activities reported by Calow and Calow (1975) for whole animal homogenates. Their activities were converted to the units used in this paper, assuming their reaction rates were linear. These activities were 15, 18, and 19 μg glucose · min^{-1} · mg protein^{-1}. They incubated their solutions at 4°C for 6 hours, a lower temperature and longer time period than used by us. Our assay was performed near field temperature. Determinations of temperature optima and seasonal changes in cellulase activity of *Lymnaea (Pseudosuccinea) columella* are in progress.

The high cellulase activity measured in *A. limosa* suggests that this species normally ingests cellulose-containing foodstuffs. If the relationship between *A. limosa* cellulase activity and assimilation efficiency is similar to that reported for other species by Calow and Calow (1975), *A. limosa* is expected to digest *Scenedesmus* with an assimilation efficiency greater than 50%.

A. limosa grazes upon filamentous green algae possessing cellulose cell walls (Kesler,

1979, 1980). *A. limosa* grazing pressure in Nonquit Pond, Rhode Island was seen to increase as these algal species decreased in abundance (Kesler, 1979). The data presented in this paper indicate that *A. limosa* is able to assimilate these algae with high efficiency, and may therefore normally select these species as food items.

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A MODIFIED SLIDE RULE FOR MEASURING SHELLS

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ABSTRACT

A modification of an inexpensive slide rule is given for measuring accurately to one decimal place, fragile mollusk shells. Measurements with the shell slide-meter can be made much quicker than with conventional ocular micrometers or vernier micrometers and calipers.

A plethora of tools are available for measuring various dimensions of mollusk shells but all are awkward, expensive and/or cumbersome to use. Also, vernier calipers may damage fragile shells if not used carefully.

A device that is easily transported and handled, inexpensive, and accurate to within one decimal place was needed to measure sphaeriid clams in the field. To meet these requirements, an inexpensive slide rule was modified and tested for accuracy and ease of use. The device is called a shell slide-meter.

Construction of Shell Slide-meter

Obtain an inexpensive plastic slide rule (ours cost \$2.65) and a 15.2 cm (6 in) long × 1.5 cm (0.59 in) wide stainless steel ruler with at least 0.5 mm divisions. Our ruler has 0.5 mm divisions for the first 5 cm and 1 mm divisions for the next 10 cm (cost = \$2.25). A strip of acrylic plastic, 8 cm long × 1.5 cm high × 0.5 cm thick is also required (cost about 20 cents).

Remove the cursor from the slide rule by filing the stops (if present) on the bottom of one end of

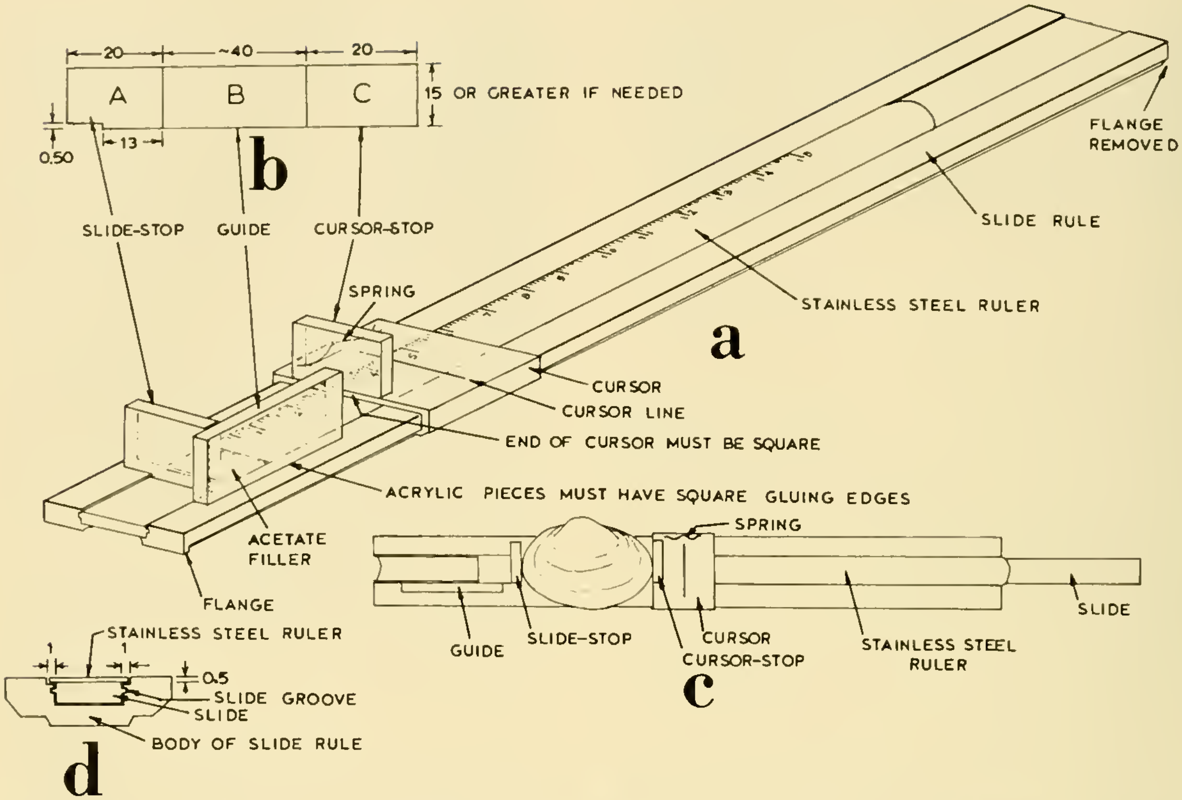

FIG. 1. *Assembly of shell slide-meter. (a) Assembled slide-meter, (b) Dimensions of acrylic stop and guide pieces, (c) Method of measuring large shells (i.e. pull slide-stop past guide), (d) Cross-sectional view of slide-meter. All measurements are in millimeters.*

the slide rule. Sand one end of the cursor square and smooth (Fig. 1a). Keeping the slide in place, evenly sand the surface of the slide rule with no. 80 sandpaper (wrapped around a block of wood) until all numbers and scales are removed. Using a router mounted on a table and a 1.27 cm (0.5 in) dia. rabbet bit, plane about 0.5 mm (or the thickness of the steel ruler) off the thickness of the slide and about 1 mm wide off the slide rule (keeping the 0.5 mm depth) on each side of the slide (i.e. the steel ruler must fit loosely in the planed portion). Plastic filings or burrs may get in the groove of the slide rule that guides the slide and impede movement of the slide. If so, remove the slide and rid the groove of any filings or burrs until the slide moves freely in the grooves (Fig. 1d).

The last step before assembly is to cut the strip of acrylic plastic into three pieces, as shown in Fig. 1b. It is extremely important that the edges of the acrylic to be glued to the slide rule be perfectly square with the faces of the acrylic pieces.

The slide-meter is now ready to assemble. With contact cement, glue the stainless steel ruler to the slide so that the "0" line of the ruler is about 3 cm from the end of the slide rule (Fig. 1a). Replace the cursor and slide it to the zero end of the ruler so that the cursor line is exactly over the "0" mark of the ruler. Tape or clamp the cursor firmly in place. With epoxy cement, or any appropriate glue (we used Krazy Glue), glue the acrylic slide-stop piece (A, Fig. 1b) to the slide so that it touches (but is not glued to) the front edge of the cursor. Next glue the acrylic cursor-stop piece (C, Fig. 1b) to the front end of the cursor so that it lies perfectly flush and square against the slide-stop piece (A) (i.e. you should not be able to see any space between the two stop pieces). Before glueing the two stop pieces, it is wise to make sure that they both sit squarely on the slide and cursor. Next, glue the

acrylic guide (B, Fig. 1b) to the top side of the slide rule, near the slide and about 3 cm from the end. Before the glue has dried thoroughly, remove the tape or clamp holding the cursor and test the slide-meter for accuracy (see below). If the cursor does not move easily, remove it from the slide and adjust the spring tension until the cursor will move with only the slightest touch. Free movement of the cursor is necessary to prevent crushing of fragile shells when the two stops are brought together (with the shell between). Finally, a 0.5 mm thick piece of acetate (or any plastic) should be cut and glued to fit the area of slide between the slide-stop and the end of the steel ruler (Fig. 1a).

Accuracy of Shell Slide-meter

The accuracy of the shell slide-meter is most easily determined by checking against gauges of known thickness (e.g. automotive ignition feeler gauges). If the slide-meter measurement does not correspond to the gauge size, either a correction factor must be applied to all slide-meter values, or the steel ruler must be removed and adjusted (if glue has not yet set too firmly). However, if all edges of the acrylic pieces are square, the slide-meter will measure accurately and there will be no need for adjustments or correction factors.

Use of Shell Slide-meter

To measure length, place the shell lengthwise between the slide- and cursor-stops. Make certain shell is properly oriented for maximum length, then pull the slide-stop toward the cursor-stop until the cursor moves. Read the length and record. The height of shells is measured in the same manner, but care is needed to ensure the shell is oriented properly (i.e. is horizontal and not tilted) for maximum height. If the slide-meter is held nearly vertical, widths are especially easy to measure because the two stops, when brought together, tend to orient the shell automatically for maximum width.

The guide of the slide-meter serves only to keep the shells between the two stops. For large shells (e.g. unionid clams), the slide-stop is pulled beyond the guide, and then the shell is placed between the slide- and cursor-stops for measurements (Fig. 1c).

Comparison with Other Devices

The reproducibility and ease of use of the shell slide-meter were tested against conventional measuring devices, including an ocular micrometer (in M8, Wild Stereomicroscope), a vernier microscope (No. 12, Precision Tool and Instrument Co., Thornton Health Surrey, England), and a vernier caliper (L.S. Starret Co., Athol, Massachusetts). Three different people measured ten sphaeriid clams *(Sphaerium rhomboideum)* for length (maximum anterior to posterior distance), width (maximum width laterally) and height (maximum ventral to dorsal distance) with each of the measuring devices. The total time to measure all ten clams for each dimension was also recorded.

The results (Table 1) show that the readability of the shell-slide meter (0.2 mm) is less than that of the other devices (up to 0.01 mm) but the reproducibility was as good (within 0.3 mm) or better than other devices, especially for widths of the clams. This resulted from the difficulty in getting the clams to stay oriented properly for maximum width using conventional devices, particularly microscopes. The greatest advantage of the shell slide-meter is the time it saves in making measurements, up to nearly one quarter of the time for lengths and heights and one sixth of the time for widths compared to microscopes. The vernier microscope is very accurate but takes considerable time to use because, like the microscope with the ocular grid, the specimens first have to be placed on a zero line; the widths are especially hard to measure because the clams must be balanced on the umbones using cotton as a base. The ocular grid has a further disadvantage in that the measurements are in ocular units which later must be converted back to millimeters. The additional time needed for this calculation is included in the Table 1 values.

The shell slide-meter also has been used with similar ease and readability for measuring freshwater snails and unionid clams. One limitation of the slide-meter, however, is it cannot be used to measure shells less than 0.5 mm wide because they tend to slip under the cursor when measuring for lengths and heights. The smallest *S. rhomboideum* that we are able to measure is

TABLE 1. Mean lengths (L), heights (H) and widths (W) and ranges (mm, in parentheses) of ten clams (*Sphaerium rhomboideum*) as measured with four instruments and average times needed to make all ten measurements for each dimension by three people.

Clam	Shell Slide-meter			Ocular Grid			Vernier Microscope			Vernier Caliper		
No.	L	H	W	L	H	W	L	H	W	L	H	W
1	11.3 (11.3-11.4)	9.1 (9.0-9.1)	6.6 (6.6-6.6)	11.74 (11.40-12.10)	9.30 (9.24-9.40)	6.77 (6.62-6.82)	11.47 (11.43-11.53)	9.15 (9.01-8.20)	6.76 (6.72-6.80)	11.5 (11.3-11.6)	9.0 (8.9-9.1)	6.7 (6.6-6.8)
2	10.8 (10.8-10.9)	9.0 (8.9-9.1)	6.0 (5.9-6.0)	10.96 (10.95-11.04)	8.85 (8.78-9.10)	6.33 (6.19-6.48)	10.93 (10.90-10.95)	9.05 (8.95-9.18)	6.15 (6.13-6.18)	10.9 (10.8-11.0)	8.9 (8.9-9.0)	6.1 (6.0-6.1)
3	9.3 (9.2- 9.3)	7.7 (7.6-7.8)	4.7 (4.6-4.8)	9.44 (9.36- 9.50)	7.84 (7.78-7.90)	4.97 (4.90-5.04)	9.24 (9.04- 9.39)	7.76 (7.64-7.89)	4.94 (4.86-5.02)	9.3 (9.2- 9.4)	7.7 (7.6-7.7)	4.9 (4.8-4.9)
4	7.7 (7.5- 7.8)	6.7 (6.6-6.8)	4.8 (3.7-4.0)	7.88 (7.78- 7.92)	6.76 (6.69-6.92)	3.95 (3.89-4.10)	7.88 (7.83- 7.95)	6.68 (6.58-6.77)	3.85 (3.70-3.98)	7.7 (7.6- 7.9)	6.8 (6.6-6.9)	3.8 (3.7-4.0)
5	7.6 (7.5- 7.7)	6.6 (6.6-6.7)	3.6 (3.6-3.7)	7.74 (7.68- 7.78)	6.30 (6.26-6.34)	3.72 (3.61-3.84)	7.72 (7.70- 7.73)	6.72 (6.63-6.80)	3.73 (3.68-3.80)	7.7 (7.7- 7.7)	6.8 (6.7-6.8)	3.7 (3.6-3.8)
6	6.8 (6.7- 6.9)	5.8 (5.7-5.9)	3.1 (3.1-3.2)	7.00 (6.93- 7.06)	5.97 (5.90-6.05)	3.64 (3.31-3.74)	7.10 (7.00- 7.14)	6.23 (6.13-6.33)	3.20 (2.97-3.40)	7.0 (7.0- 7.1)	6.0 (5.6-6.2)	3.4 (3.2-3.6)
7	6.6 (6.6- 6.7)	5.7 (5.5-5.8)	3.0 (3.0-3.1)	6.70 (6.62- 6.77)	5.90 (5.90-5.90)	3.17 (3.02-3.24)	6.87 (6.85- 6.95)	5.83 (5.73-5.83)	3.24 (3.20-3.30)	6.6 (6.4- 6.8)	5.7 (5.5-6.0)	8.1 (2.9-3.2)
8	6.2 (6.0- 6.3)	5.5 (5.4-4.4)	2.8 (2.7-2.8)	6.31 (6.19- 6.41)	5.45 (5.33-5.59)	2.96 (2.88-3.03)	6.38 (6.36- 6.40)	5.58 (5.53-5.54)	2.93 (2.84-3.04)	6.4 (6.4- 6.4)	5.6 (5.6-5.7)	2.9 (2.8-2.9)
9	4.4 (4.4- 4.5)	3.7 (3.6-3.7)	1.8 (1.7-1.8)	4.68 (4.16- 4.75)	3.70 (3.61-3.89)	1.95 (1.84-2.16)	4.66 (4.63- 4.70)	3.82 (3.63-4.05)	1.85 (1.72-1.90)	4.7 (4.6- 4.8)	3.8 (3.6-4.1)	1.8 (1.7-2.1)
10	4.0 (3.9- 4.2)	3.3 (3.3-3.4)	1.3 (1.2-1.3)	4.04 (4.03- 4.05)	3.51 (3.44-3.60)	1.47 (1.44-1.50)	4.13 (4.12- 4.15)	3.49 (3.48-3.50)	1.47 (1.43-1.50)	4.1 (4.0- 4.1)	3.5 (3.4-3.5)	1.4 (1.4-1.5)
Ave. Time (min)	2.78	3.26	2.60	4.83	5.06	7.25	11.93	11.83	15.18	4.88	5.24	4.63
Range (min)	2.50-3.10	3.10-3.50	2.50-2.80	3.45-5.10	4.33-6.50	6.25-8.25	8.50-14.55	8.25-15.75	9.90-17.75	4.25-5.50	4.50-5.50	4.50-4.90

about 2.5 mm long, (H = 2.0 mm, W = 1.0 mm) which is a larval stage.

ACKNOWLEDGMENTS

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ON THE IDENTITY OF THE GASTROPOD, *MUREX HEROS* FULTON, 1936

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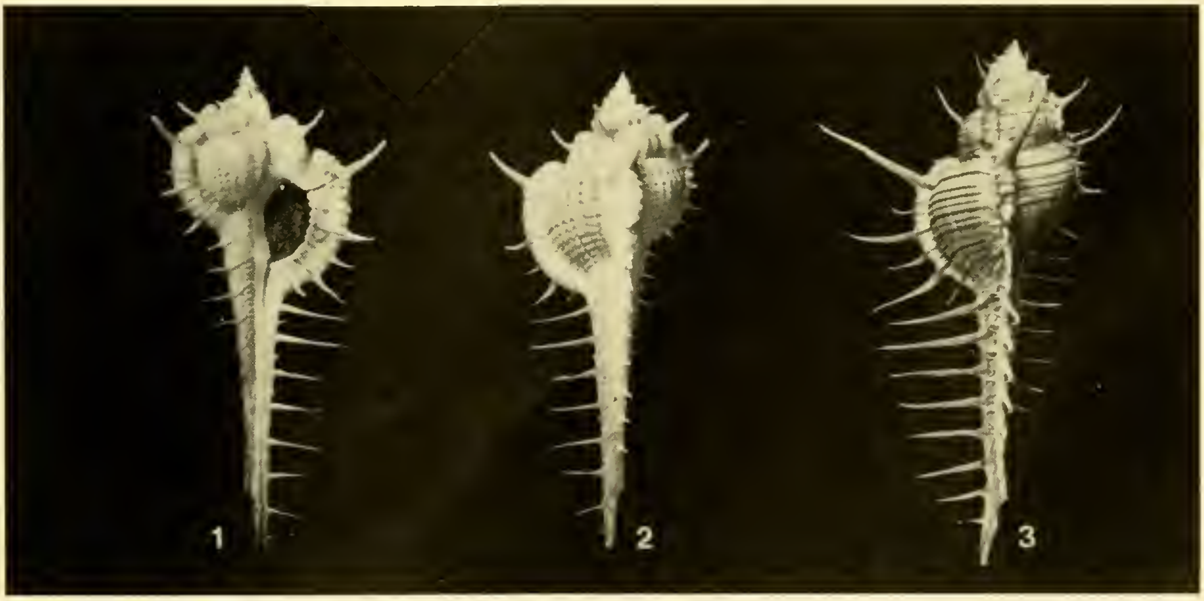
In the course of dredging operations in the Solomon Islands, several specimens of an unusual *Murex* were brought to light. Robert Morrison of Sarasota, Florida, sent me a specimen for identification. Additional specimens were provided by Brian Bailey.

A search of the literature showed these specimens to be referable to *Murex heros* Fulton, 1936. This identification was confirmed by comparison of these specimens with the holotype [British Museum (Natural History) Reg. No. 1936.5.26.1].

Murex heros was originally described from a single broken specimen which lacked locality data. Vokes (1971, p. 57) recognized this taxon as valid, but subsequent workers (Fair, 1976, p. 48; Radwin and D'Attilio, 1976, p. 74) synonymized this species with *M. troscheli* Lischke, 1868. Fulton (1936, p. 10) stated that *M. heros* "is allied to *troscheli* Lischke, but is more solid and readily separated by its much more numerous and finer spirals. The varices are not in a straight axial line but are nearer so than in *troscheli.*"



FIGS. 1–3. Murex heros *Fulton, 1936. Dredged in 180–200 m, off Russel Island, Solomon Islands, on fine sand and rubble bottom (0.6 ×).* 3, Murex troscheli *Lischke, 1968. Dredged in 60 m, off An Ping Island, Taiwan (0.4 ×).*

Examination of a series of specimens of each taxon showed that *M. heros* is indeed more solid than *M. troscheli*, but neither the number of spiral threads nor the arrangement of the varices vary significantly between the species. *Murex heros* does differ from *M. troscheli* by having more pronounced axial sculpture, and by lacking the uninterrupted dark brown coloration on the spiral cords which is characteristic of *M. troscheli*.

The distribution of *M. troscheli* has been reported as ranging from S.E. Japan to the Central Philippines (Radwin and D'Attilio, 1976, p. 74). Hinton (1972, p. 34) reports *M. troscheli* from New Guinea. The type locality for *M. heros* is here designated as Russel Island, Solomon Islands.

As more material comes to light, *M. heros* may prove to be a subspecies of *M. troscheli*.

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THE FRESHWATER MUSSELS (BIVALVIA: UNIONIDAE) OF THE CLINTON RIVER, MICHIGAN, WITH COMMENTS ON MAN'S IMPACT ON THE FAUNA, 1870–1978

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ABSTRACT

Collections taken from 1870 to 1933 in Michigan's Clinton River system are compared with the results of a 1977–78 survey. Since 1933, the drainage basin on the edge of metropolitan Detroit has undergone extensive development and urbanization. Although urban pollution has destroyed the mussel fauna in parts of the basin, most streams with rural watersheds still contain healthy mussel populations. Of the original fauna of 31 species, 26 species of mussels remained in 1978, including four species on Michigan's rare and endangered species list. Especially notable is the continued presence of Carunculina glans, *which has not been found alive anywhere since 1948.*

Studies prior to World War II showed western Lake Erie, Lake St. Clair, and their tributaries to have a rich mussel fauna (Walker, 1892; Clark and Wilson, 1912; Goodrich, 1914, 1932; LaRocque and Oughton, 1937; van der Schalie, 1938a; Brown *et al.*, 1938; Clark, 1944). In the last few years, man's activities in the surrounding areas of the watershed have caused locally severe water quality problems for aquatic life (e.g., van der Schalie, 1938b, 1958; Trautman, 1957; Carr and Hiltunen, 1965; Grant, 1973). Recent survey work (Stansbery, 1960; van der Schalie, 1970; Clarke, 1973; Clark, 1977; Strayer, 1979) has not been sufficient to define the present state of mussel populations in the area.

One river system in the area, the Clinton River, was intensively surveyed in 1977–78 in order to determine the present status of mussel

populations there. Special attention was given to the species considered by the state of Michigan to be rare or endangered (van der Schalie, 1975; Michigan Department of Natural Resources, 1976). In this paper, I present the results of that survey, and compare them where possible to earlier collections made in the Clinton. Another paper (Strayer, in preparation) treats some ecological aspects of the survey results.

THE STUDY AREA

The Clinton River, a tributary of Lake St. Clair, drains 1977 km² just north of metropolitan Detroit, Michigan (Fig. 1). For the purposes of this paper, the stream and its tributaries may be conveniently divided into a number of sections. The *upper mainstem*, from Pontiac upstream, is a small (< 10 m wide), clear stream flowing across a flat outwash plain. Its course is interruped by a number of lakes and marshy areas. Flowing across a series of end moraines from Pontiac to the Macomb County line, the *middle mainstem* has a relatively high gradient (ca. 2.7 m/km), resulting in a predominance of gravelly substrata. It receives two major tributaries: *Paint Creek* and *Stony Creek*. These creeks are clear, swift streams of fairly high gradient (2–4 m/km). Below the Macomb County line, the *lower mainstem* runs across the flat plain left by a postglacial predecessor to the Great Lakes. This stream is 15–70 m wide, and is often muddy, especially below the confluence of *Red Run*. Red Run and its tributaries have been greatly altered by human activities, so I cannot describe their original natural condition. A large tributary stream, the *North Branch*,

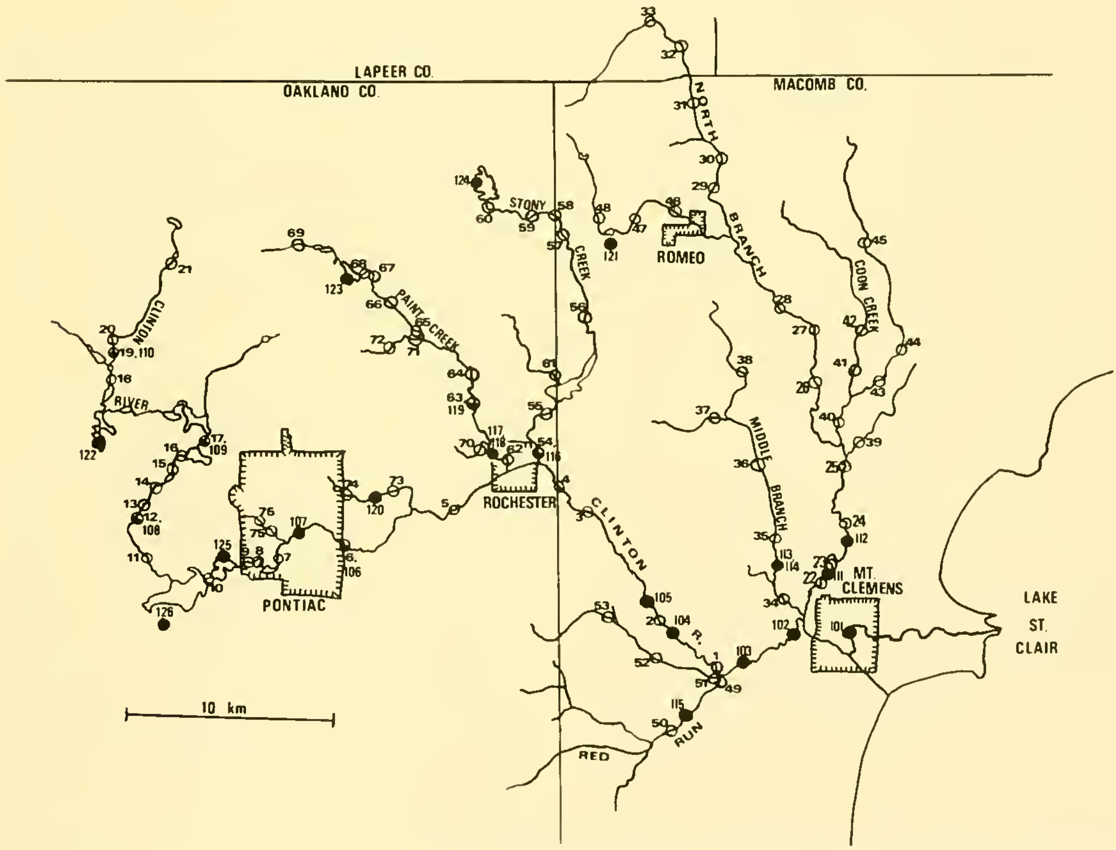

FIG. 1. *The Clinton River system, southeastern Michigan. Black circles (Nos. 101–126) are sites collected prior to 1935, open circles (Nos. 1–76) were visited in 1977–78, and half-filled circles were collected in both periods. Station numbers and locations correspond to those given in Tables 1 and 2. Modified from Nowlin (1973).*

enters the lower mainstem at Mt. Clemens. The *upper North Branch,* from its source to station 27, is a small clear stream of low gradient. *East Pond Creek* is its only major tributary. Because the latter stream drains end moraines, it is markedly different than others of the North Branch drainage, which all drain lake plain, and it resembles Stony Creek, both physically and faunistically. The *lower North Branch* receives a number of tributaries, the most important of which are Coon Creek, Deer Creek, and the Middle Branch. The Middle Branch, equal in name only to the North Branch and main branch, is merely a large muddy creek, even at its lower reaches. Coon Creek is an extreme example of a stream draining clay soils of low infiltration capacities. Although it has very high flows (50–75 m^3/sec) in the spring, it is reduced in late summer to a series of stagnant pools. Below its confluence with Coon Creek, the North Branch is a small (6–12 m wide), muddy river, in which riffles separate long slow pools. All of the streams here are slightly alkaline hardwater streams. A report by Nowlin (1973) contains further details on the chemistry, hydrology, and drainage basins of these streams.

All of the streams have been more or less affected by man. Pontiac Creek, an extreme case, has been straightened and paved in concrete. Considerable amounts of domestic and industrial wastes have been discharged into the Clinton River, especially at Pontiac (population of 85,279), Rochester (pop. 7,054) and Mt. Clemens (pop. 20,476), and into Red Run from Detroit's northern suburbs. Red Run has, in addition, been straightened and leveed. The North Branch has a largely agricultural watershed, and receives the silt, fertilizers, and agricultural chemicals associated with farming. There are two fairly large reservoirs (40 and 200 ha) on Stony Creek, and dams pond smaller portions of many of the other streams here. Moreover, it should be kept in mind that all streams have received the general disturbances associated with intensive human use of their watersheds (from land clearing, domestic sewage, road salts, construction activities, etc.).

MATERIALS AND METHODS

There are no previous publications on the mussel fauna of the Clinton River, although it is discussed peripherally in Goodrich (1932) and van der Schalie (1938a). Most of the previous work on the Clinton consists of a series of unpublished collections housed in the University of Michigan Museum of Zoology (UMMZ). These include scattered collections from the period ca. 1870–1925, as well as rather thorough collections of 11 sites taken by Dr. Henry van der Schalie on 22–23 June 1933. All of these records are summarized in my Table 1.

We visited 76 sites in the Clinton River basin during periods of low, clear water in 1977–78 (Fig. 1), handpicking mussels at each site until we felt that all species had been found. At eight stations (10, 16, 17, 21, 22, 24, 31 and 53) problems such as access, depth, turbidity and time prevented us from making complete collections. Voucher specimens from the 1977–78 survey are in the UMMZ.

The lower North Branch (stations 22–24) presented special problems, for it was turbid when we collected it. Here, we felt for mussels with our hands and feet, and the slowness of this procedure prevented us from getting the large collections that we desired. As a result, we may have missed some rare species in this stretch.

For a *rough* measure of the abundance of a species at a site, divide the number of living specimens found by the approximate area searched.

RESULTS AND DISCUSSION

The Clinton River mussel fauna included 31 species (Tables 1 and 2). This is a large number of species, even for a stream in the Erie-St. Clair Basin (cf. van der Schalie, 1938a; Clarke, 1973; Clark, 1977), and appears to be greater than that of any other stream in the Great Lakes drainage, the Maumee River excepted. The North Branch drainage alone had 26 species, an exceptionally large number for so small a stream (drainage area of 731 km^2). Other parts of the basin were very rich as well (e.g., stations 9 and 102).

Seven members of the Clinton basin mussel fauna are listed as rare, threatened, or endangered by the state of Michigan (van der Schalie, 1975; Michigan Department of Natural

TABLE 1. *Locality records of mussels from the Clinton River, Michigan prior to 1935. From collections at the Univ. Michigan Mus. Zoology.*

	101. Clinton R. @ Mt. Clemens	102. Clinton R. - 1 mi. above mouth Middle Br.	103. Clinton R. - 3 mi. above Mt. Clemens	104. Clinton R. - 3 mi. below Utica	105. Clinton R. @ Utica	106. Clinton R. - just below Pontiac	107. Clinton R. @ Pontiac	108. Clinton R. - nw of Crescent Lake	109. Clinton R. @ Waterford	110. Clinton R. @ Clarkston	111. N. Br. Clinton R. - 2 mi. n of Mt. Clemens	112. N. Br. Clinton R. - Macomb Co.	113. Mid. Br. Clinton R. - 2 mi. below Waldenburg	114. Creek (Mid. Br.?) - 6 mi. nw of Mt. Clemens	115. Branch Clinton R. (Red Run?) betw. Warren & Utica	116. Stony Cr. - 1 mi. ne of Rochester	117. Paint Cr. - n of Rochester	118. Paint Cr. - 1 mi. nw of Rochester	119. Paint Cr. - se of Orion Jct.	120. Galloway Cr. - ne of Pontiac	121. Cusic Lake	122. Maysday (= Maceday?) Lake	123. Lake Orion	124. Lakeville Lake	125. Sylvan Lake	126. Orchard Lake
Amblema plicata Say	X	X	X	X	X						X	X														
Fusconaia flava (Raf.)	X	X	X	X	X						X	X	X	X	X											
Quadrula pustulosa (Lea)		X																								
Quadrula quadrula (Raf.)																										
Cyclonaias tuberculata (Raf.)		X																								
Elliptio dilatata Raf.		X			X			X								X	X	X							X	
Pleurobema cordatum coccineum (Conrad)	X	X	X					X			X	X														
Alasmidonta calceolus (Lea)	X				X			X			X			X	X	X		X		X						
Alasmidonta marginata Say	X	X			X			X									X		X							
Anodonta grandis Say	X	X	X		X	X		X	X	X	X	X									X	X	X	X		
Anodonta imbecilis Say																										
Anadontoides ferussacianus (Lea)	X			X	X						X		X	X	X	X	X	X	X							
Lasmigona complanata (Barnes)		X		X							X	X														
Lasmigona compressa (Lea)	X	X		X	X		X	X			X		X		X			X	X							
Lasmigona costata (Raf.)	X	X			X						X															
Strophitus undulatus (Say)		X		X	X		X			X	X	X	X		X	X	X									
Actinonaias carinata (Barnes)		X	X	X	X						X	X														
Carunculina glans (Lea)							X																			
Carunculina parva (Barnes)		X																								
Dysnomia torulosa rangiana (Lea)							X																			
Dysnomia triquetra (Raf.)		X	X					X			X															
Lampsilis fasciola (Raf.)		X			X		X	X			X															
Lampsilis ovata ventricosa (Barnes)	X	X	X	X	X																					X
Lampsilis radiata siliquoidea (Barnes)	X	X	X	X	X						X	X											X			
Ligumia nasuta (Say)	X	X									X															
Ligumia recta (Lamarck)	X	X	X		X																					
Obovaria subrotunda (Raf.)	X	X																								
Proptera alata (Say)				X																						
Villosa fabalis (Lea)	X						X	X			X															
Villosa iris (Lea)	X	X			X	X		X	X		X	X	X													
Ptychobranchus fasciolare (Raf.)	X	X			X			X			X	X														

Resources, 1976). Foremost among these is *Carunculina glans* (listed as "rare"), which is said by Stansbery (1970) to be "on the verge of extinction". The single colony at Pontiac (station 9) has been known since well before Walker's (1892) publication, although it seems to have been ignored by later authors. *C. glans* is known from Michigan only from this colony, a single shell from the Cass River (UMMZ records), and a single old valve from Macon Creek (Strayer, 1979). The record of *C. glans* from Otter Creek, Michigan (Goodrich, 1932; van der Schalie, 1975; Clark, 1977) is based upon a misidentified lot of *Carunculina parva* (UMMZ #99303) and cannot be regarded as valid. Recent records from other parts of its range are lacking; the most recent record of which I am aware is Clark's (1977) collection of a single specimen from Fish Creek, Indiana, in 1948.

C. glans is presently restricted to an 80 m long stretch of stream in a residential-commercial section of Pontiac (a four-lane highway bridge bisects at site!), although it is quite abundant there. It is unclear to me why the species is so

TABLE 2. *Results of the 1977–78 survey work. The number of live specimens found is recorded. d = only dead shells found; D = not found alive, but presumed living at the site.*

	1. Clinton R. @ Hayes Rd	2. Clinton R. @ Dodge Park #8	3. Clinton R. @ Ryan Rd.	4. Clinton R. @ 23 Mi. Rd.	5. Clinton R. @ Crooks Rd.	6. Clinton R. @ Opdyke Rd.	7. Clinton R. @ Gillespie St.	8. Clinton R. - ¼ mi. below Orchard Lk Rd	9. Clinton R. - Orchard Lk Rd.	10. Clinton R. @ Cass Lk Rd.
Approximate area searched (m^2)	1000	1000	500	500	500	100	100	1200	400	500
Amblema plicata	d									
Fusconaia flava										
Quadrula pustulosa										
Quadrula quadrula										
Cyclonaias tuberculata										
Elliptio dilatata		d			d			d	44	d
Pleurobema cordatum coccineum		d						d	2	d
Alasmidonta calceolus		d								d
Alasmidonta marginata		d								
Anodonta grandis								4	19	d
Anodonta imbecillis								3	16	
Anodontoides ferussacianus										
Lasmigona complanata										
Lasmigona compressa										
Lasmigona costata		d								
Strophitus undulatus								d	d	
Actinonaias carinata										
Carunculina glans								d	24	
Carunculina parva										
Dysnomia torulosa rangiana										
Dysnomia triquetra									d	
Lampsilis fasciola									d	
Lampsilis ovata ventricosa	d	d							4	
Lampsilis radiata siliquoidea		d							2	d
Ligumia nasuta										
Ligumia recta										
Obovaria subrotunda										
Proptera alata										
Villosa fabalis									D	
Villosa iris	d	d						1	8	
Ptychobranchus fasciolare									16	d

	11. Clinton R. @ Cooley Lk. Rd.	12. Clinton R. @ Elizabeth Lk. Rd.	13. Clinton R. @ Pontiac Lk Rd.	14. Clinton R. @ Crescent Lk Rd.	15. Clinton R. @ Hatchery Rd.	16. Clinton R. @ US-10	17. Clinton R. @ Walton Blvd.	18. Clinton R. just above Green's Lake	19. Clinton R. @ M-15 s of Clarkston	20. Clinton R. @ M-15 in Clarkston	21. Clinton R. @ Hoyt Rd.
Approximate area searched (m^2)	700	475	900	300	1000	--	200	450	250	50	20
Amblema plicata											
Fusconaia flava											
Quadrula pustulosa											
Quadrula quadrula											
Cyclonaias tuberculata											
Elliptio dilatata	16	41	11	24	1			14			
Pleurobema cordatum coccineum	6	30	7	26	7						
Alasmidonta calceolus	d		d		d						
Alasmidonta marginata		d									
Anodonta grandis	5	14	5	19	30	1	4			d	
Anodonta imbecillis	1		1	5	31						
Anodontoides ferussacianus											
Lasmigona complanata											
Lasmigona compressa		1									
Lasmigona costata											
Strophitus undulatus	9	2	5	4	11	D		26			
Actinonaias carinata											
Carunculina glans											
Carunculina parva											
Dysnomia torulosa rangiana											
Dysnomia triquetra	5	2	2	3							
Lampsilis fasciola	d	d	d	6							
Lampsilis ovata ventricosa											
Lampsilis radiata siliquoidea		1			d	1		3			
Ligumia nasuta											
Ligumia recta											
Obovaria subrotunda											
Proptera alata											
Villosa fabalis	d	D	D								
Villosa iris	d	10	1	1	2		d	1		d	
Ptychobranchus fasciolare	13	36	5	24	1						

	22. N. Br. Clinton R. @ Dunham Rd.	23. N. Br. Clinton R. @ Hall Rd	24. N. Br. Clinton R. - 1¼ mi. s of 23 Mi. Rd.	25. N. Br. Clinton R. @ 24 Mi. Rd.	26. N. Br. Clinton R. @ 27 Mi. Rd.	27. N. Br. Clinton R. @ 29 Mi. Rd.	28. N. Br. Clinton R. @ 30 Mi. Rd.	29. N. Br. Clinton R. @ 34 Mi. Rd.	30. N. Br. Clinton R. @ Armada Center Rd.
Approximate area searched (m^2)	--	175	--	275	2500	800	1600	375	325
Amblema plicata		52		4	1				
Fusconaia flava	d				3				
Quadrula pustulosa		1							
Quadrula quadrula		7							
Cyclonaias tuberculata									
Elliptio dilatata					2		d		
Pleurobema cordatum coccineum		7		18	D		d	D	d
Alasmidonta calceolus							d	D	d
Alasmidonta marginata		1					d		
Anodonta grandis	d	8	d	6	4	1			
Anodonta imbecillis									
Anodontoides ferussacianus		1	d	1	7	3	3	14	0
Lasmigona complanata	4	27	11	30	35	1	5		19
Lasmigona compressa		1	1	4	1	1	1	10	25
Lasmigona costata		16		6	6				
Strophitus undulatus		1		28	45	13	1	1	3
Actinonaias carinata	d	18	d	47	8	1	d		
Carunculina glans									
Carunculina parva									
Dysnomia torulosa rangiana									
Dysnomia triquetra		d							
Lampsilis fasciola				D	2		d		
Lampsilis ovata ventricosa		1		1	8	1			
Lampsilis radiata siliquoidea	d	3	1	8	15	d			d
Ligumia nasuta									
Ligumia recta									
Obovaria subrotunda									
Proptera alata		1							
Villosa fabalis									
Villosa iris		d		7	1	d	1	6	5
Ptychobranchus fasciolare		5		67	1				

	31. N. Br. Clinton R. @ McKay Rd.	32. N. Br. Clinton R. @ Hough Rd.	33. N. Br. Clinton R. @ M-53 in Almont	34. Mid. Br. Clinton R. - 1¼ mi. above mouth	35. Mid. Br. Clinton R. @ 21 Mi. Rd.	36. Mid. Br. Clinton R. @ 24 Mi. Rd	37. Mid. Br. Clinton R. @ Hayes Rd.	38. Healy Drain @ Romeo Plank Rd.
Approximate area searched (m^2)	75	150	200	120	225	300	--	600
Amblema plicata				1				
Fusconaia flava				3	1	16		
Quadrula pustulosa								
Quadrula quadrula								
Cyclonaias tuberculata								
Elliptio dilatata								
Pleurobema cordatum coccineum								
Alasmidonta calceolus			d	2	d	d		1
Alasmidonta marginata								
Anodonta grandis				17				
Anodonta imbecillis								
Anodontoides ferussacianus	3		33	5	d	d		18
Lasmigona complanata	1			22		d		
Lasmigona compressa	3		1	1	d	d		d
Lasmigona costata								
Strophitus undulatus						2		
Actinonaias carinata								
Carunculina glans								
Carunculina parva								
Dysnomia torulosa rangiana								
Dysnomia triquetra								
Lampsilis fasciola								
Lampsilis ovata ventricosa								
Lampsilis radiata siliquoidea				22				
Ligumia nasuta								
Ligumia recta								
Obovaria subrotunda								
Proptera alata								
Villosa fabalis								
Villosa iris								
Ptychobranchus fasciolare								

	39. Deer Cr. @ Chapman Rd.	40. Coon Cr. - ½ mi. above mouth	41. Coon Cr. @ North Ave	42. Coon Cr. @ 29 Mi. Rd.	43. E. Br. Coon Cr. - 1 mi. n of 26 Mi. Rd.	44. E. Br. Coon Cr @ New Haven Rd.	45. E. Br. Coon Cr. @ 32 Mi Rd.	46. E. Pond Cr @ M-53	47. E. Pond Cr. @ 33 Mi. Rd. - downstream crossing	48. E. Pond Cr. @ 33 Mi. Rd. - upstream crossing
Approximate area searched (m^2)	100	150	200	200	500	200	100	120	200	100
Amblema plicata		1			D					
Fusconaia flava		D	d	d	3					
Quadrula pustulosa										
Quadrula quadrula										
Cyclonaias tuberculata										
Elliptio dilatata								73	23	
Pleurobema cordatum coccineum								2	7	D
Alasmidonta calceolus					d			22	d	
Alasmidonta marginata										
Anodonta grandis		23	D	2	12	1				
Anodonta imbecillis										
Anodontoides ferussacianus	0	d		d	5		0	26	13	8
Lasmigona complanata		3	2		14					
Lasmigona compressa		d						5		
Lasmigona costata		d								
Strophitus undulatus		d			3					
Actinonaias carinata										
Carunculina glans										
Carunculina parva					d					
Dysnomia torulosa rangiana										
Dysnomia triquetra										
Lampsilis fasciola										
Lampsilis ovata ventricosa										
Lampsilis radiata siliquoidea		10			26	1				
Ligumia nasuta										
Ligumia recta										
Obovaria subrotunda										
Proptera alata										
Villosa fabalis								12	5	
Villosa iris		1								
Ptychobranchus fasciolare										

	49. Red Run @ mouth of Plum Brook	50. Red Run @ Maple Lane	51. Plum Brook @ mouth	52. Plum Brook @ Dodge Park Rd.	53. Plum Brook @ 18½ Mi. Rd.	54. Stony Cr. @ Parkdale Rd.	55. Stony Cr. @ Winkler Mills Rd.	56. Stony Cr. - 100 yds. below Inwood Rd.	57. Stony Cr. @ 32 Mi. Rd.	58. Stony Cr. @ 33 Mi. Rd.
Approximate area searched (m^2)	--	--	--	100	100	300	250	200	45	110
Amblema plicata										
Fusconaia flava				d					4	3
Quadrula pustulosa										
Quadrula quadrula										
Cyclonaias tuberculata										
Elliptio dilatata							d	d	120	65
Pleurobema cordatum coccineum							d	2		
Alasmidonta calceolus								1	5	d
Alasmidonta marginata						4	2			
Anodonta grandis						4	8	2		
Anodonta imbecillis										
Anodontoides ferussacianus					D	5		d		
Lasmigona complanata										
Lasmigona compressa						15	11	21	26	2
Lasmigona costata										
Strophitus undulatus				d		36	9	d	19	4
Actinonaias carinata										
Carunculina glans										
Carunculina parva										
Dysnomia torulosa rangiana										
Dysnomia triquetra										
Lampsilis fasciola										
Lampsilis ovata ventricosa										
Lampsilis radiata siliquoidea				d						
Ligumia nasuta										
Ligumia recta										
Obovaria subrotunda										
Proptera alata										
Villosa fabalis								1	2	5
Villosa iris										
Ptychobranchus fasciolare										

	59. Stony Cr. @ Brewer Rd. (e of Townsend Rd.)	60. Stony Cr. @ Milmine Rd.	61. W. Br. Stony Cr. @ Metropark Rd.	62. Paint Cr. @ Walton Blvd	63. Paint Cr. @ Dutton Rd.	64. Paint Cr. @ Orion Rd	65. Paint Cr. @ Adams Rd.	66. Paint Cr. @ Kern Rd.	67. Paint Cr. @ Atwater Rd.	68. Paint Cr. @ Lake Orion dam
Approximate area searched (m^2)	100	100	500	300	250	500	500	1000	400	350
Amblema plicata										
Fusconaia flava	19									
Quadrula pustulosa										
Quadrula quadrula										
Cyclonaias tuberculata										
Elliptio dilatata	55		2		d		d			d
Pleurobema cordatum coccineum	1								d	d
Alasmidonta calceolus	2					d				
Alasmidonta marginata										
Anodonta grandis									16	4
Anodonta imbecillis										
Anodontoides ferussacianus									1	
Lasmigona complanata										
Lasmigona compressa					d	d			2	D
Lasmigona costata										
Strophitus undulatus	1					d	d			
Actinonaias carinata										
Carunculina glans										
Carunculina parva										
Dysnomia torulosa rangiana										
Dysnomia triquetra										
Lampsilis fasciola										
Lampsilis ovata ventricosa										
Lampsilis radiata siliquoidea										
Ligumia nasuta										
Ligumia recta										
Obovaria subrotunda										
Proptera alata										
Villosa fabalis	5					d				
Villosa iris										
Ptychobranchus fasciolare										

	69. Paint Cr. @ Newman Rd.	70. Sargent Cr. @ Livernois Rd.	71. Trout Cr. below Adams Rd.	72. Trout Cr. @ Greenshield Rd.	73. Galloway Cr. @ Squirrel Rd.	74. Galloway Cr. @ Opdyke Rd.	75. Pontiac Cr @ Johnson Ave.	76. Pontiac Cr @ Fairy St.
Approximate area searched (m^2)	350	100	175	50	200	100	--	--
Amblema plicata								
Fusconaia flava								
Quadrula pustulosa								
Quadrula quadrula								
Cyclonaias tuberculata								
Elliptio dilatata								
Pleurobema cordatum coccineum								
Alasmidonta calceolus		d	2		d			
Alasmidonta marginata								
Anodonta grandis	1		5					
Anodonta imbecillis								
Anodontoides ferussacianus	32	D	13					
Lasmigona complanata								
Lasmigona compressa			1					
Lasmigona costata								
Strophitus undulatus								
Actinonaias carinata								
Carunculina glans								
Carunculina parva								
Dysnomia torulosa rangiana								
Dysnomia triquetra								
Lampsilis fasciola								
Lampsilis ovata ventricosa								
Lampsilis radiata siliquoidea								
Ligumia nasuta								
Ligumia recta								
Obovaria subrotunda								
Proptera alata								
Villosa fabalis								
Villosa iris								
Ptychobranchus fasciolare								

restricted; ecological conditions at several sites in the upper mainstem appear to be suitable for its propagation. If *C. glans* is as rare as it appears to be, it might be well worth finding out more about its ecology and fish host relations in order to establish colonies at other sites.

Dysnomia torulosa rangiana ("rare") was found by earlier collectors in a section of stream at Pontiac that today contains more shopping carts than mussels (stations 6–8). It may persist in low numbers in another part of the basin, though, for Dr. Carol Stein of Ohio State University (personal communication) found this mussel at station 23 in 1965, although I found no trace of it there in 1978. Its original range in the Great Lakes area included the basins of Lakes Erie and St. Clair, where it was always rare, and it is very scarce today (Stansbery, 1970; Clarke, 1973). Records from the Lake Michigan basin (Johnson, 1978) are erroneous; *D. t. rangiana* is a species of the Wabash and Erie-St. Clair basins and never reached drainages further west. Johnson's single record is from "Grand Rapids, Michigan", a locality known for its unreliability (cf. Heard, 1962, p. 142).

Dysnomia triquetra ("threatened") still lives in the upper mainstem and, perhaps, the lower North Branch, but has been eliminated from the lower mainstem. It is found in scattered localities in the Great Lakes basin, but is characteristically uncommon (van der Schalie, 1936, 1938a; Brown *et al.*, 1938; Robertson and Blakeslee, 1948; Clarke, 1973; Strayer, 1979).

Villosa fabalis ("rare") has a distribution similar to that of *Dysnomia triquetra* in the Clinton, and is likewise uncommon. It has rarely been found alive in the Great Lakes system recently (Clarke, 1973).

Although *Lampsilis fasciola* ("threatened") was uncommon and restricted in the Clinton in 1977–78, it is still met with regularly in other streams of the Erie-St. Clair basin (Clarke, 1973; Clark, 1977; Strayer, 1979). *L. fasciola* was more common and widespread in the Clinton basin before 1935.

Both *Cyclonaias tuberculata* ("threatened") and *Obovaria subrotunda* ("endangered") are now apparently extinct in the Clinton, having been restricted to the lower mainstem. *C. tuberculata* is still scattered in streams of the Great Lakes basin (van der Schalie, 1970; Clarke, 1973; Clark, 1977; Strayer, 1979). In the Erie-St. Clair system, *O. subrotunda* has been eliminated from most of its former range (but see Clarke, 1973; Clark, 1977). The Lake Michigan drainage is sometimes included as part of the range of *O. subrotunda* (Burch, 1975; van der Schalie, 1975) on the strength of a single lot (UMMZ #25) from Grand Rapids, but considerations similar to those discussed under *Dysnomia torulosa rangiana* suggest that this record should be rejected.

Two other species *(Ligumia recta* and *Ligumia nasuta)* found by earlier workers were not collected in 1977–78. Both species were most abundant in the lower mainstem and were probably eliminated from that stretch with the gross pollution there after 1933.

We found two species *(Anodonta imbecilis* and *Quadrula quadrula)* that were not found by earlier collectors, but it is likely that this reflects the incompleteness of earlier work rather than any range extensions of these species.

The entire fauna of the mainstem from Pontiac downstream was destroyed in the period 1933–1977; the amount of weathering of the few shells found there in 1977–78 suggests that this occurred early in the period. A similar situation was found in Red Run and lower Paint Creek in 1977–78. The only living mollusks found in these streams were the gastropods *Physa sp.* and *Ferrissia sp.* Red Run and the mainstem have received considerable domestic and industrial pollution: Grant (1973) documents problems with low dissolved oxygen, high ammonia, and heavy metals, and these streams have doubtless received other substances capable of killing mussels over the years.

The situation in Paint Creek is more puzzling. It is managed for trout, and casual observations in 1978 showed it to have good water quality and a rich fauna of aquatic arthropods. It is not clear to me what destroyed the mussel fauna there and what is preventing its return from Trout Creek and upper Paint Creek.

The faunas of two other stream stretches appear to have been affected by man. In 1978, stations 55–56 in lower Stony Creek were littered with dead shells of *Elliptio dilatata*, but I found no live specimens there. Other mussel species

were fairly abundant, so it appears that *Elliptio* was selectively extirpated there. I have not been able to locate any sources of pollution or disturbance between stations 56 and 57, although it is possible that the building of the Stony Creek reservoirs in 1961 and 1963 had something to do with the conditions there.

Two stations (27 and 28) in the North Branch contained very few living mussels, all of which were younger than four years old in 1978. Large numbers of weathered shells in this stretch point to the existence of a diverse fauna in earlier years. It seems likely that some pollutant (originating from Romeo, most likely) destroyed the fauna some years ago, and the mussels are only now beginning to return with the abatement of the pollution. I have been unsuccessful in locating such a source in Romeo, however.

Clearly, man's activities have had a devastating effect on some mussel populations in this area. On the other hand, many sites visited in 1977–78 (most of the North Branch, Stony Creek, and upper mainstem drainages) still had healthy mussel assemblages, both in terms of mussel densities and species diversities. It appears that these sites have retained their original faunas. Furthermore, at those stations for which previous collections are available for comparison, I usually found that in 1977–78 mussel species were present in roughly the same proportions as in the years prior to 1935. This parallels the findings of Larimore and Smith (1963), who said of their collections of Illinois fishes:

> In view of the great changes in land use, in the stream courses, and in the stream habitats . . . it is indeed astounding that many of our species were still present in the same streams . . . and probably in approximately the same numbers . . . as . . . previously.

The factor determining the present state of a mussel fauna is the degree to which *urban* pollution has affected the stream stretch. All stream stretches subjected to urban pollution in the Clinton system have lost their mussel faunas, whereas most of the streams free of urban pollution still contain dense and diverse mussel beds, in spite of disturbances from other sources there.

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A NEW GENUS, SPECIES AND SUBSPECIES OF OOCORYTHIDAE (GASTROPODA: TONNACEA) FROM THE WESTERN ATLANTIC

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ABSTRACT

Relationships within the Tonnacea are discussed briefly; the Oocorythidae are confirmed at full family status. Oocorys umbilicata *and* O. bartschi clericus *are described as new. The gross anatomy of* O. umbilicata *is described.* Oocorys bartschi bartschi *is now known from throughout the Gulf of Mexico and northeast Florida, and the range of* O. caribbaea *is extended from south of Cuba to the Bahamas.* Hadroocorys, *new genus, is proposed for* O. verrilli *and* O. tosaensis.

The deep waters of the Gulf of Mexico, Caribbean Sea and Bahama Islands have been well sampled by the Bureau of Commercial Fisheries (now National Marine Fisheries Service) and the University of Miami. Among the molluscan specimens obtained, the genus *Oocorys* Fischer, 1883, is well represented. Notable among these collections are those from the Tongue of the Ocean (TOTO), Bahamas, in which three species (two new) are represented, two in surprising numbers. This allows more extensive examination and assessment of intraspecific variations and suprageneric relationships of *Oocorys* than was possible when Turner (1948) published her monograph of the group.

Collections on which this report is based are housed primarily in the U.S. National Museum of Natural History, Washington, D.C., and the Rosenstiel School of Marine and Atmospheric Science, University of Miami. Institutional abbreviations used herein are: National Museum of Natural History (*USNM*); Rosenstiel School

of Marine and Atmospheric Science, University of Miami (*UMML*); Museum of Comparative Zoology, Harvard University (*MCZ*); Academy of Natural Sciences, Philadelphia (*ANSP*); Marine Research Laboratory, Florida Department of Natural Resources (*FSBC I*). Holotypes of the new taxa are deposited in the USNM.

Oocorythidae Fischer, 1885

The systematic position of *Oocorys* within the Tonnacea has been unsettled for many years. Fischer (1885), in proposing the family name Oocorythidae, allied *Oocorys* to the Tritonidae (= Cymatiidae), mainly on the basis of opercular characters. Several subsequent authors (Tryon, 1885; Schepman, 1909; Tomlin, 1927; Thiele, 1929; Wenz, 1941; Kuroda and Habe, 1957; Kilias, 1962; Bayer, 1971) have also considered the *Oocorys*-group a valid family, usually placing it near the Cassidae. Watson (1886) allocated *Oocorys* to the Doliidae (= Tonnidae) and was followed by Turner (1948), Keen (1971), and Abbott (1974). Dall (1909) discussed at length the relationships of the Cassidae and concluded that *Oocorys* and *Galeodea* Link, 1807, could not be separated from the true cassids. Turner (1948) concluded that neither the presence or absence of an operculum nor difference in radular tooth morphology was sufficient to distinguish groups at the family level, and that shell morphology was the most reliable character for inferring relationships within the Tonnacea. Consequently, she assigned *Oocorys* to the Oocorythinae in the Tonnidae because of the superficial resemblance of some *Oocorys* to *Eudolium* Dall, 1889.

Of all the proposed classifications, that of Thiele (1929) is probably most correct at the family level. He used six families: Oocorythidae, Cassididae (= Cassidae), Cymatiidae, Bursidae, Doliidae (= Tonnidae), and Pirulidae (= Ficidae). The distinctive saddle-shaped rhachidian teeth of the Tonnidae (Fig. 1F) and Bursidae (Fig. 1G) immediately separate these two families from the others. Radulae of the other four tonnacean families have less striking but still diagnostic characters. The Ficidae (Fig. 1D) have a subquadrate rhachidian, a large lateral with denticles along both sides of the cusp, and a large marginal which is serrate on the outer edge. The Cymatiidae (Fig. 1E) have a laterally excavated, subquadrate rhachidian, a large lateral with the cusp serrate on the outer side and two strong but simple marginals (inner marginal occasionally with denticles). The Cassidae (Fig. 1H) and the Oocorythidae (Fig. 1A-C) have similar radulae, but the cassids have marginals which are denticulate at the tip while the Oocorythidae have simple marginals, the innermost of which may or may not have 1-3 small denticles along its inner side.

In the Oocorythidae there appear to be four or five genera: *Oocorys*, *Hadroocorys* n. gen., *Dalium* Dall, 1889, *Galeoocorys* Kuroda and Habe, 1957, and perhaps *Galeodea*. I have not seen a radula of *Galeodea*, but if the figure in Thiele (1929) (see Fig. 1I is accurate, the genus is best assigned to the Oocorythidae.

Genus *Oocorys* Fischer, 1883

Diagnosis—Shell medium to large in size (35 to over 120 mm in length), thin but strong, imperforate or umbilicate. Sculpture of strong spiral ridges; axial sculpture reduced or absent. Aperture large, broadly lanceolate to ovate; outer lip thin, usually reflected, occasionally weakly crenulate; parietal area with a thin callus, often with spiral sculpture showing through. Operculum corneous, paucispiral. Radula taenioglossate; rhachidian quadrangular; lateral large, denticulate; marginals strong, arcuate, with or without denticles. Eyes absent.

Type-species—*Oocorys sulcata* Fischer, 1883; by monotypy.

Remarks—Since Turner's (1948) monograph of the western Atlantic species of *Oocorys*, some material with soft parts has been obtained. An examination of the gross anatomy (see *O. umbilicata*) reveals a typically tonnacean organization, agreeing very closely with the arrangement exhibited by the other families (Amaudrut, 1898; Weber, 1927; Houbrick and Fretter, 1969). The operculum of *Oocorys* may be of value in distinguishing between species. Besides the general size and shape, both of which are somewhat variable, the size and shape of the muscle attachment scar may be of specific value. I have illustrated the opercula of those species

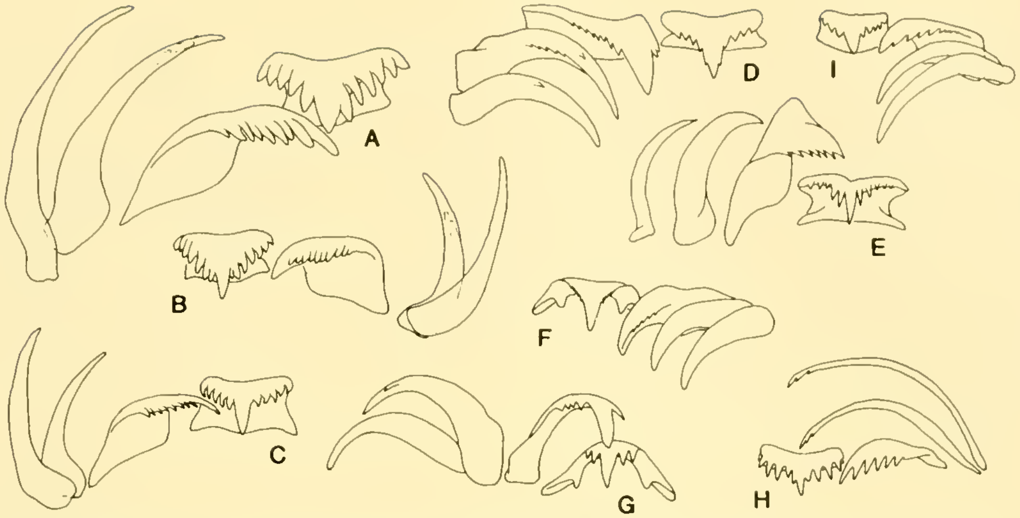

FIG. 1. *Tonnacean radulae:* **A)** Oocorys bartschi clericus *Quinn, subsp. nov. (P-781, UMML 30–8259);* **B)** Oocorys caribbaea *Clench and Aguayo, 1939 (CI-382, UMML 30–8252);* **C)** Oocorys umbilicata *Quinn, sp. nov. (CI-306, UMML 30–8176);* **D)** *Ficidae,* Ficus reticulata *Lamarck, 1816* (=Ficus communis *Röding, 1798);* **E)** *Cymatiidae,* Cymatium muricinum *(Röding, 1798);* **F)** *Tonnidae,* Tonna perdix *(Linnaeus, 1758);* **G)** *Bursidae,* Bursa crumena *(Lamarck, 1816);* **H)** *Cassidae,* Cassis cornuta *(Linnaeus, 1758);* **I)** *Oocorythidae (?),* Galeodea echinophora *(Linnaeus, 1758). Figs.* **D, F, G, H,** *and* **I,** *from Thiele, 1929; Fig.* **E** *from Cernohorsky, 1967. Not to scale.*

available to me which were not illustrated by Turner (1948) or Bayer (1971) (see Fig. 2).

Turner (1948) discussed or listed 18 species and subspecies of *Oocorys s.l.* which she considered valid (there were 22 nominal species-group taxa). Of these, nine were described from the North Atlantic, three from the eastern Pacific, and the other six from Indonesia and the eastern Indian Ocean. Subsequently, a species was described from Japan (*O. tosaensis* Habe and Azuma, 1959), but that species and *O. verrilli* (Dall, 1889) are here treated as generically separate. With the addition of the new species and subspecies described in this paper, there are 19 species and subspecies of *Oocorys,* of which ten are known from the North Atlantic. *Benthodolium* Verrill and Smith, 1884, has been used as a monotypic subgenus of *Oocorys.* The primary distinguishing character, the presence of an umbilicus, is useful only at the species level. *Benthodolium* is here considered a synonym of *Oocorys.*

Oocorys umbilicata sp. nov.

Figs. 1C; 2A, B; 3; 4.

Description–Shell length to about 55 mm, ovate, inflated, umbilicate, with numerous spiral cords; color white under thin brown periostracum. Protoconch whorls 2–2½, small, smooth. Teleoconch whorls weakly shouldered, with numerous strong, rounded spiral cords, 28–33 on last whorl, 10–14 on penultimate whorl, somewhat more widely spaced at shoulder and near umbilicus, weak or absent near suture. Aperture broadly lanceolate; columella twisted to left anteriorly; parietal area with fairly thick glaze through which spiral sculpture often shows; outer lip flared, thickened, usually weakly crenulate; siphonal canal short, broad. Operculum ovate, subspiral, corneous, brown.

Animal (in alcohol) uniformly cream-colored. Foot truncate anteriorly, tapering gradually to broadly rounded posterior margin. Cephalic tentacles large, stout, evenly tapered to bluntly rounded tips, bases close-set; eyes absent. Osphradium large, broad, brown, bipectinate, lying at base of short siphon. Ctenidium large, whitish. Hypobranchial gland inconspicuous. Pallial sperm duct closed, thin-walled, becoming dorsally open groove distally, continued along anteroventral surface of penis; penis large,

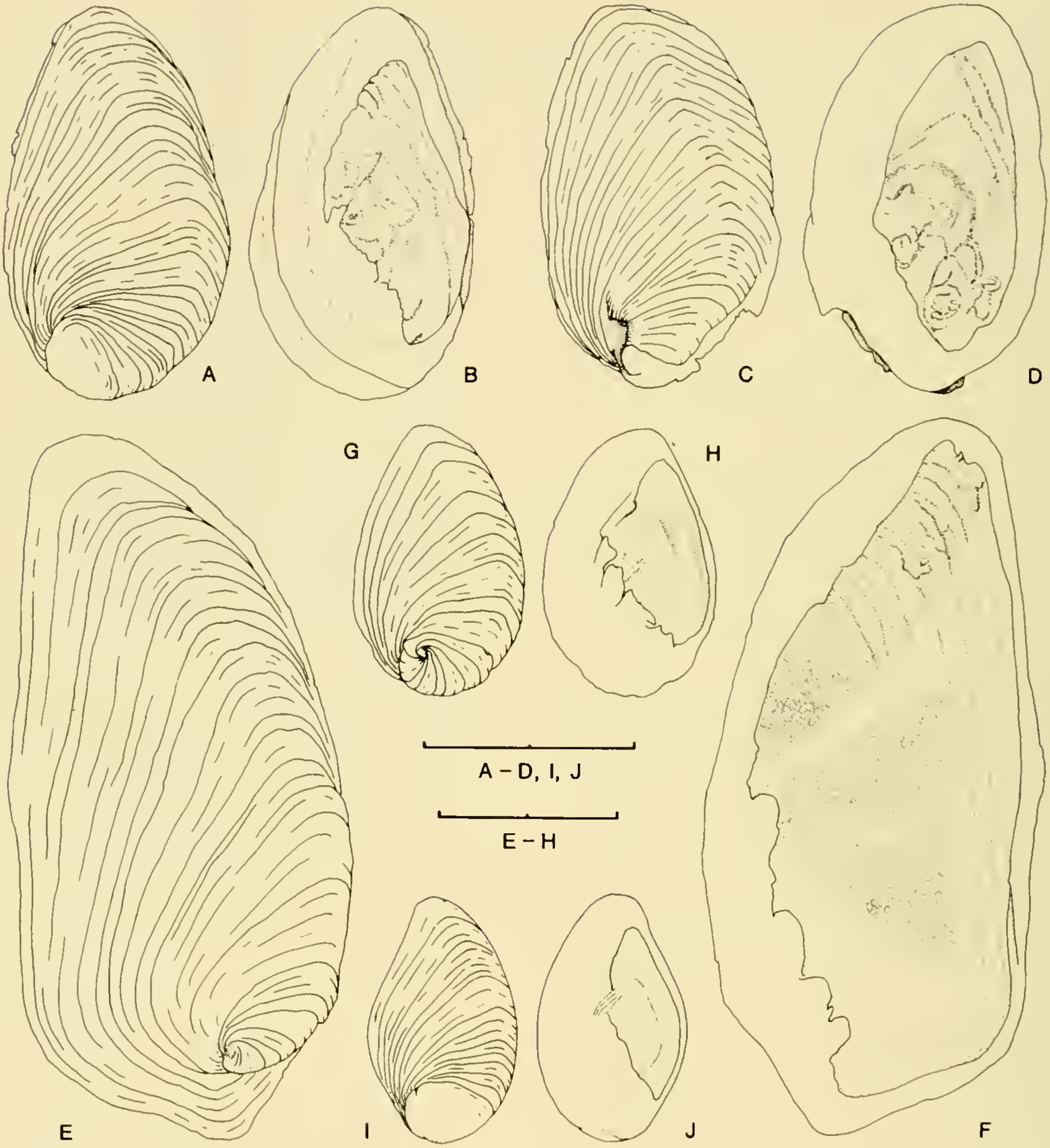

FIG. 2. *Opercula of* Oocorys *species:* **A, B)** Oocorys umbilicata *Quinn, sp. nov. (paratype, CI-306);* **C, D)** Oocorys bartschi clericus *subsp. nov. (paratype, P-781, UMML 30-8259);* **E, F)** Oocorys bartschi bartschi *Rehder, 1943 (ANTILLAS sta., UMML 30-481);* **G, H)** Oocorys sulcata *Fischer, 1883 (P-18, UMML 30-8287);* **I, J)** Oocorys caribbaea *Clench and Aguayo, 1939 (CI-382, UMML 30-8252). Scale lines are 10 mm.*

somewhat spatulate, with area of low (glandular?) folds on distal ¼, abutting sperm groove (Fig. 3). Organization of cephalic cavity typically tonnacean. Proboscis pleurembolic, long, with small buccal mass at tip; in fully contracted state, mouth lies just inside opening of proboscis sheath. Odontophore very small; pair of chitinous jaws present, each roughly triangular in

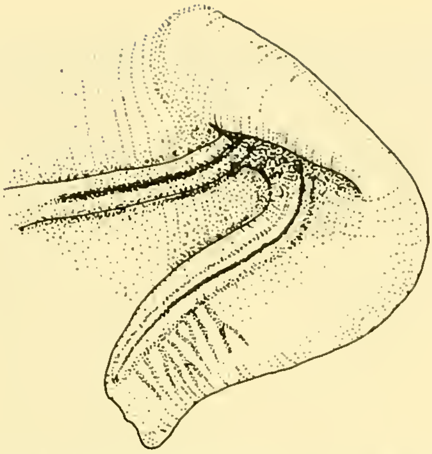

FIG. 3. *Penis of* Oocorys umbilicata *Quinn, sp. nov., as seen from right side of body. Note open sperm groove and glandular (?) area near tip. Enlarged by approximately 10×.*

shape, covered by numerous scales. Salivary glands very large, occupying most of cephalic cavity, covering mid-esophagus dorsally and laterally; left salivary gland larger than and mostly lying posterior to right; salivary ducts prominent, attached to anterior esophagus, passing through nerve ring and entering respective glands subterminally. Esophagus lying along floor of proboscis, passing through nerve ring and along floor of cephalic cavity to posterior end; mid-esophagus with large esophageal gland along right side; gland brown, transversely folded internally. Organs of visceral mass not examined due to poor preservation.

Holotype–USNM 784592. Height 48.8 mm; maximum width 33.5 mm.

Type locality–COLUMBUS ISELIN sta. CI-306, 24°06.2′N, 77°17.9′W to 24°07.2′N, 77°18.2′W, 1379-1408 m, 4–5 Apr. 1975. (Tongue of the Ocean, east of Andros Island, Bahamas).

Paratypes–COMBAT sta. 356, 33°31′N, 76°35′W, 366 m, 1 spec., USNM 715016.–COLUMBUS ISELIN sta. CI-306 with same data as holotype, 2 spec., USNM 795646; 1 spec., MCZ 288820; 1 spec., ANSP A8345; 20 spec., UMML 30–8176.–COLUMBUS ISELIN sta. CI-14, 23°35′N, 77°11′W to 23°33′N, 77°09′W, 1246 m, 2 spec., FSBC I 23779; 19 spec., UMML 30–8177.–TOTO, Northeast Providence Channel and Exuma Sound, 1234–2780 m, 55 lots, 223 spec., UMML 30-8178 to 30–8233.

Distribution–This species is known from off Charleston, South Carolina, and the deep-water basins of the northern Bahamas; depth range is from 366 m (off Charleston, South Carolina) to 2780 m in the Northeast Providence Channel, Bahamas. *O. umbilicata* appears from our collecting records to be most abundant in depths of 1300–1400 m.

Remarks–Superficially, *O. umbilicata* resembles *O. sulcata* Fischer, 1883, and *O. abyssorum* (Verrill and Smith, 1884). *O. umbilicata* is more strongly shouldered than either *O. sulcata* or *O. abyssorum*. *O. sulcata* is not umbilicate, and *O. abyssorum* has a much thinner shell with much narrower spiral cords. *O. umbilicata* is the most common species of prosobranch in the TOTO collections. Most of the specimens obtained were dead shells, but at least 25-30 were collected with soft parts. The gross anatomy shows the species to be typically tonnacean. The feeding habits of *O. umbilicata* may be similar to those of species in other tonnacean families which feed on echinoderms, polychaetes, sipunculans, or other mollusks (see Houbrick and Fretter, 1969). Although all of these food types were available, *O. umbilicata* was most often collected with sabellariid and onuphid (*Hyalinoecia* sp.) polychaetes and a large sipunculan which inhabited dead *Oocorys* shells (pers. observations), suggesting that *Oocorys* eats worms. Unlike species of *Bursa*, which are vermivores (Houbrick and Fretter, 1969), species of *Oocorys* possess a pair of strong jaws and probably bite off pieces of the prey rather than swallowing the whole animal.

Oocorys caribbaea Clench and Aguayo, 1939

Figs. 1B; 2I, J; 5.

Oocorys sulcata caribbaea Clench and Aguayo, 1939: 192, pl. 29, fig. 3.

Oocorys (Oocorys) caribbaea: Turner, 1948: 184, pl. 83, figs. 3, 4; Abbott, 1974: 169, fig. 1791.

Description–See Clench and Aguayo (1939) and Turner (1948).

Material examined–Tongue of the Ocean, Bahamas, (TOTO), COLUMBUS ISELIN stations:

CI-309, 23°45.1′N, 76°46.7′W, 1319–1313 m, 1 spec., UMML 30-8234.

CI-368, 23°43.2′N, 76°50.5′W, 1352–1342 m, 2 spec., UMML 30-8235.

CI-307, 23°30.5′N, 76°55.5′W, 1321–1307 m, 2 spec., UMML 30-8236.

CI-14, 23°33′N, 77°09′W, 1246 m, 3 spec., UMML 30-8237.

CI-311, 23°39.2′N, 77°34.4′W, 1353–1360 m, 2 spec., UMML 30-8238.

CI-314, 23°46.5′N, 77°18.8′W, 1374–1360 m, 2 spec., UMML 30-8239.

CI-40, 23°46′N, 76°58′W, 1317 m, 1 spec., UMML 30-8240.

CI-9, 23°50′N, 77°04′W, 1318 m, 2 spec., UMML 30-8241.

CI-326, 23°53.8′N, 76°16.8′W, 1383 m, 2 spec., UMML 30-8242.

CI-306, 24°07.2′N, 77°18.2′W, 1379–1408 m, 1 spec., UMML 30-8243.

CI-61, 24°33′N, 77°28′W, 1463 m, 2 spec., 30-8244.

Exuma Sound, Bahamas:

CI-275, 24°38.8′N, 76°23.8′W, 1632–1637 m, 9 spec., UMML 30-8245.

CI-68, 24°25′N, 76°09′W, 1664 m, 14 spec., UMML 30-8246.

CI-70, 24°27′N, 76°16′W, 1673 m, 3 spec., UMML 30-8247.

CI-274, 24°30.8′N, 76°18.8′W, 1701 m, 1 spec., UMML 30-8248.

CI-192, 24°20.8′N, 76°21′W, 1760 m, 1 spec., UMML 30-8249.

CI-278, 23°54.6′N, 75°57.3′W, 1779–1771 m, 3 spec., UMML 30-8250.

CI-284, 23°54.3′N, 75°57.8′W, 1781–1772 m, 3 spec., UMML 30-8251.

CI-382, 23°55.4′N, 75°59.3′W, 1763 m, 1 spec., UMML 30-8252.

CI-338, 24°00.8′N, 75°49.5′W, 1899–1880 m, 2 spec., UMML 30-8253.

CI-383, 23°49.8′N, 75°51′W, 1844–1817 m, 1 spec., UMML 30-8254.

CI-381, 24°22.1′N, 76°10.5′W, 1758–1767 m, 2 spec., UMML 30-8255.

Remarks–Prior to the University of Miami expeditions to the Bahamas, *O. caribbaea* was known only from six specimens collected at three localities off the southern coast of Cuba (Turner, 1948). The collections from the Bahamas contain 60 specimens from 22 localities making it one of the more common species in TOTO and Exuma Sound, occurring at depths of 1300–1800 meters. These specimens exhibit remarkably little variation in shell characters, varying slightly in spire height, strength of axial sculpture and number of spiral cords. The ovate operculum (Fig. 2I, J) is rather thin and flexible, with a muscle scar of the same general size and shape as those of *O. sulcata* (Fig. 2G, H) and an *Oocorys* species from the Caribbean tentatively identified by Bayer as *O. sulcata* (Baker, 1971: p. 42, figs. 18, 22B). One live-collected specimen retained the periostracum on the 3-whorled protoconch, exhibiting fairly strong axial riblets and weak spiral threads.

Oocorys bartschi bartschi Rehder, 1943

Figs. 2E, F; 6.

Oocorys bartschi Rehder, 1943: 197, pl. 10, fig. 16; 1954: 472.

Oocorys (Oocorys) bartschi: Turner, 1948: 182, pl. 82, figs. 1, 2; Abbott, 1974: 168, fig. 1789.

Material examined–Gulf of Mexico: W. L. Schmidt coll., S. of Tortugas, Florida, 144–256 m, 1 spec., USNM 535689 (holotype).

Henderson coll., Florida, 1 spec., USNM 417859 (paratype).

W. L. Schmidt coll., Tortugas, Florida, 238–205 m, 1 spec., USNM 709509.

ANTILLAS sta., upper Gulf of Mexico, 1 spec., UMML 30-481.

OREGON sta. 4945, 29°39′N, 86°48′W, 219 m, 1 spec., USNM 751945.

OREGON II sta. 11195, 29°20′N, 86°52′W, 662 m, 2 spec., USNM 751944.

OREGON II sta. 10404, 29°17′N, 87°03′W, 755 m, 1 spec., USNM 751936.

OREGON II sta. 13474, 29°33′N, 87°09′W, 327 m, 1 spec., USNM 751939.

OREGON sta. 281, 29°38′N, 87°16′W, 205 m, 1 spec., USNM 637429.

OREGON sta. 1450, 29°17′N, 87°41′W, 439 m, 1 spec., USNM 714929.

OREGON II sta. 11580, 29°11′N, 87°55′W, 640 m, 1 spec., USNM 751938.

OREGON sta. 3652, 29°13′N, 87°57′W, 457 m, 1 spec., USNM 758937.

FIGS. 4-8. *Shells of* Oocorys *and* Hadroocorys: **4)** Oocorys umbilicata *Quinn, sp. nov. (CI-306, USNM 784592, holotype);* **5)** Oocorys caribbaea *Clench and Aguayo, 1939 (CI-309, UMML 30-8234);* **6)** Oocorys bartschi bartschi *Rehder, 1943 (South of Tortugas, Florida, USNM 535689, holotype);* **7)** Oocorys bartschi clericus *Quinn, subsp. nov. (OREGON sta. 3601, USNM 751953, holotype);* **8)** Hadroocorys verrilli *(Dall, 1889) (ALBATROSS sta. 2120, USNM 87208, holotype). All figures life size.*

OREGON sta. 1571, 29°10′N, 88°07′W, 457 m, 1 spec., USNM 751932.

OREGON II sta. 11202, 29°12′N, 88°08′W, 356 m, 1 spec., USNM 751933.

OREGON sta. 4157, 29°10′N, 88°12′W, 347 m, 1 spec., USNM 751931.

OREGON sta. 3221, 29°09′N, 88°11′W, 466 m, 1 spec., USNM 751940.

OREGON sta. 482, 28°57′N, 88°42.5′W, 384 m, 1 spec., USNM 637431.

OREGON II sta. 10441, 26°05′N, 96°14′W, 137 m, 4 spec., USNM 751947.

OREGON sta. 4807, 23°30′N, 97°11′W, 731 m, 4 spec., USNM 751952.

East Florida:

COMBAT sta. 190, 29°55′N, 80°11′W, 329 m, 1 spec., USNM 714995.

Remarks—Collections made by the Bureau of Commercial Fisheries over the last twenty years contain many specimens of this species. This new material shows that *O. bartschi bartschi* is found throughout the Gulf of Mexico, in the Straits of Florida, and off northeast Florida, usually in about 200–500 meters. It attains a length of over 130 mm and varies considerably in the elevation of the spire, inflation of the whorls, and number of spiral cords on the last whorl (36–46). (See Remarks under *O. bartschi clericus*).

Oocorys bartschi clericus subsp. nov.

Figs. 1A; 2C, D; 7.

Description—Shell large, to 91.9 mm, thin but solid, moderately inflated, non-umbilicate, sculptured by numerous spiral cords; color white under moderately thick, brown periostracum. Protoconch small, smooth, about 2 whorls. Teleoconch of about 6–6½ weakly shouldered whorls; last whorl with 32–41 strong spiral cords, strongest near shoulder; subsutural area constricted and appressed to preceding whorl, slightly concave, with 1–4 weak cords. Aperture ovate, weakly lirate within; columella arcuate, rather strongly twisted to left anteriorly; parietal area with thin wash of callus. Outer lip flared, slightly thickened, weakly crenulate. Siphonal canal short, broad, open. Operculum ovate, subspiral, muscle-attachment scar fairly large.

Holotype—USNM 751953. Height 69.3 mm, maximum width 43.4 mm.

Type locality—OREGON sta. 3601, off Santa Catalina, Panamá, 9°07′N, 81°10′W, 731 m, 31 May 1962, 40′ otter trawl.

Paratypes—TOTO:

COLUMBUS ISELIN sta. CI-16, 23°37′N, 77° 18′W, 732 m, 2 spec., UMML 30–8256.

COLUMBUS ISELIN sta. CI-21, 24°28′N, 77° 25′W, 1554 m, 1 spec., UMML 30–8257.

COLUMBUS ISELIN sta. CI-309, 23°45.1′N, 76°46.7′W, 1319–1313 m, 1 spec., UMML 30–8258.

Southwestern Caribbean Sea:

PILLSBURY sta. P-781, 11°34.5′N, 73°20′W, 567–531 m, 2 spec., UMML 30–8259.

OREGON sta. 4859, 11°09′N, 74°27′W, 329–356 m, 2 spec., USNM 751955.

OREGON sta. 4841, 11°10′N, 74°29′W, 411 m, 9 spec., USNM 751954.

OREGON sta. 4854, 11°11′N, 74°29′W, 548 m, 2 spec., USNM 751957.

OREGON II sta. 10260, 11°03′N, 75°18′W, 366 m, 1 spec., USNM 751956.

OREGON sta. 4880, 10°24′N, 75°50′W, 347–356 m, 3 spec., USNM 751958.

PILLSBURY sta. P-445, 9°02′N, 81°24′W, 342–346 m, 2 spec., UMML 30–3667.

Distribution—This subspecies occurs in the Tongue of the Ocean, Bahamas, and the southwestern Caribbean from off Santa Marta, Colombia, westward to Golfo de los Mosquitos, Panamá.

Remarks—The shell of *O. bartschi clericus* is very similar to that of the nominate subspecies, but is generally smaller, less inflated, has fewer spiral cords, and has the subsutural "collar". However, since there are specimens intermediate between the two taxa (*e.g.*, *O. bartschi bartschi*, USNM 751944; *O. bartschi clericus*, UMML 30–3667) and there is apparent geographical segregation, I am treating *clericus* as a subspecies of *O. bartschi*. There appear to be some differences in the relative size and shape of the muscle scar of the operculum between the subspecies, but too few examples of opercula are known (three of each) to draw strong conclusions (see Fig. 2). The published figure of the radula of *O. bartschi s.s.* (Turner, 1948) does not correspond to that of *O. b. clericus* (Fig. 1A), differing in having a rhachidian with a rounded base, laterals denticulate on the inner edge of the cusp, and marginals lacking denticles. A future investigation with more live-collected specimens may well prove that *O. bartschi clericus* is a separate species, but such separation is not warranted by the present material.

Hadroocorys gen. nov.

Eudolium: Dall, 1889: 233 (*partim*); Kilias, 1962: 16 (*partim*).

Oocorys: Turner, 1948: 185 (*partim*); Habe and Azuma, 1959: 116; Abbott, 1974: 169 (*partim*).

Diagnosis–Oocorythidae with thick, heavy shell; outer lip varicose, denticulate; columellar lip with heavy, strongly ridged callus; aperture constricted posteriorly to form "anal notch"; anterior canal short, narrow, constricted by callus.

Type-species–Dolium (Eudolium) Verrilli Dall, 1889; herein designated.

Gender–Feminine.

Remarks–In view of the overall conservatism of the Oocorythidae, *Hadroocorys* is a very distinctive group. Although the spiral sculpture is typically oocorythid, the heavy shell and apertural crenulation separate it from all other genera of Oocorythidae. *Hadroocorys* is represented by only two known species, *H. verrilli* (Dall, 1889) and *H. tosaensis* (Habe and Azuma, 1959).

Hadroocorys verrilli (Dall, 1889)
Fig. 8.

Dolium (Eudolium) verrillii Dall, 1889: 233, pl. 35, fig. 12.
Oocorys (Oocorys) verrillii: Turner, 1948: 185, pl. 84, figs. 1, 2; Abbott, 1974: 169, fig. 1792.
Tonna (Eudolium) verrillii: Kilias, 1962: 16, fig. 12-2.

Description–See Dall (1889) and Turner (1948).

Material examined–ALBATROSS sta. 2120, 11°07′N, 62°14′30″W, 133 m, 1 spec., USNM 87208 (holotype).

Hadroocorys tosaensis (Habe and Azuma, 1959)

Oocorys tosaensis Habe and Azuma, 1959: 116, pl. 12, fig. 3; Habe, 1964: 67, pl. 20, fig. 2.

Description–See Habe and Azuma (1959).

Remarks–The holotype is presumably in the National Science Museum, Tokyo, Japan. To my knowledge, it is the only specimen of this species. *H. tosaensis* is very similar to *H. verrilli,* differing only in having a distinct umbilicus.

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SUBSPECIES OF THE GASTROPOD, *LITTORINA SCABRA*

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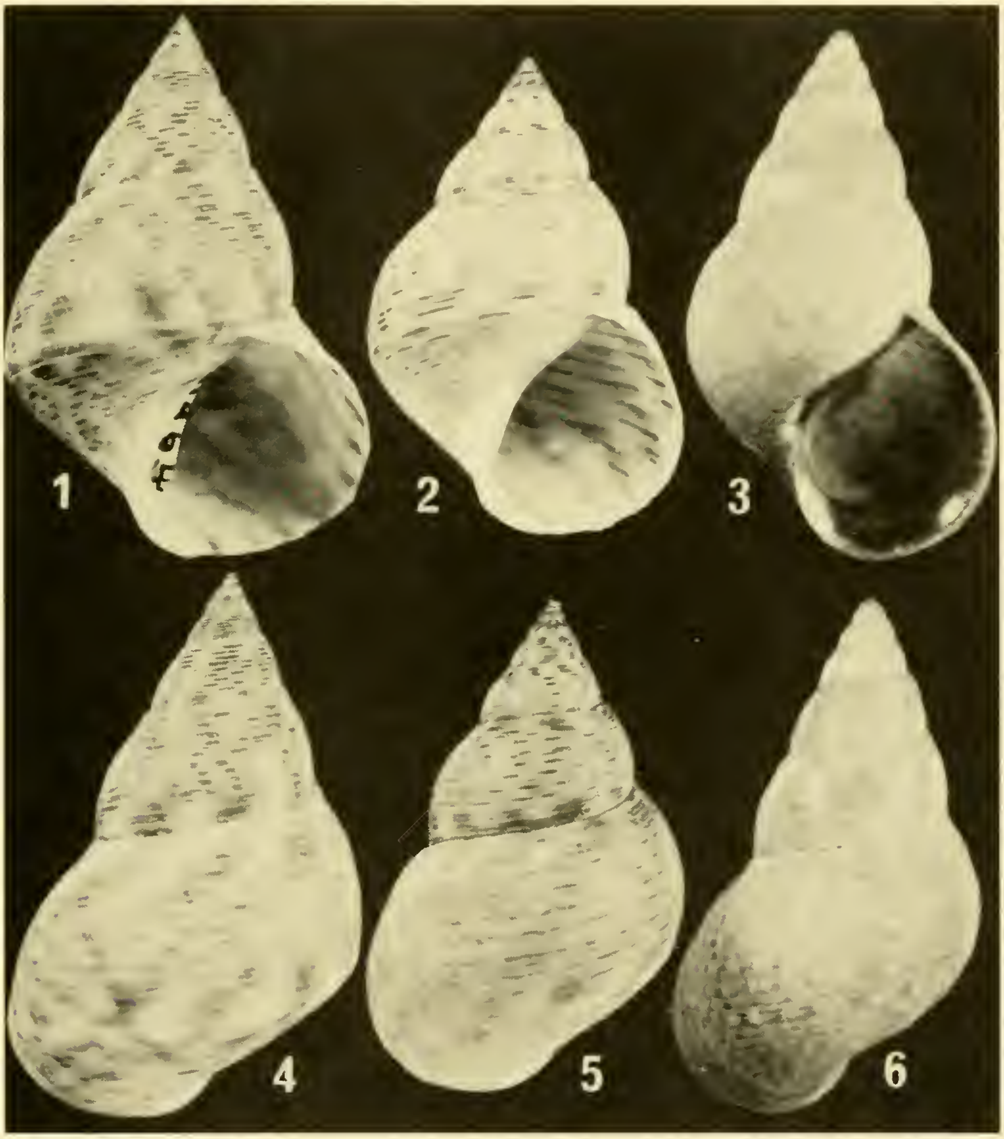
Although the subspecies concept presents a number of problems which must be overcome by the systematist in arriving at a defensible classification, it may be very useful in expressing the characteristics of a polytypic species (Mayr, 1969). It was with that objective in mind that I suggested that *Littorina scabra* (Linné, 1758) is a pantropical, polytypic species consisting of 3 subspecies: *L. scabra scabra*, (Indo-Pacific), *L. scabra aberrans* (Philippi, 1846) (east Pacific), and *L. scabra angulifera* (Lamarck, 1822) (east and west Atlantic) (Rosewater, 1963, 1967, 1970, 1972a, 1972b, 1978, 1979 and 2 papers in press). The three subspecies are very close in morphology, ecology, and in what is known of their life history, and I believe there is little doubt they are, in fact, related specifically.

One has little difficulty separating *L. scabra aberrans* from the other two, but *L. scabra scabra* and *L. scabra angulifera* are so close that it is difficult to distinguish them satisfactorily (see Figs. 1–6). They are all geographically isolated, except for the reported introduction of *L. scabra angulifera* into the east Pacific (Bequaert, 1943), which appears not to have resulted in its establishment there. Their morphological differences were pointed out by Rosewater (1970, pp. 456, 458). All three subspecies live on mangrove (personal observations), although both *L. scabra scabra* and *L. scabra angulifera* may be found living on wharf pilings or on seawalls above the water line. *Littorina scabra angulifera* is also reported to occur on *Spartina* by Gallagher and Reid (1974). The latter two subspecies are ovoviviparous and release young in the swimming



FIGS. 1–6. *Subspecies of the* Littorina scabra *species group.* **1** *and* **4**, L. scabra scabra *(Linné, 1758) from Madras, India (USNM 701964; 33 mm length).* **2** *and* **5**, L. scabra angulifera *(Lamarck, 1822) from Isle of Capri, Collier County, Florida (USNM 637271; 25.9 mm length).* **3** *and* **6**, L. scabra aberrans *Philippi, 1846, from Farfan Beach, Panama (USNM 380675; 18.7 mm length).*

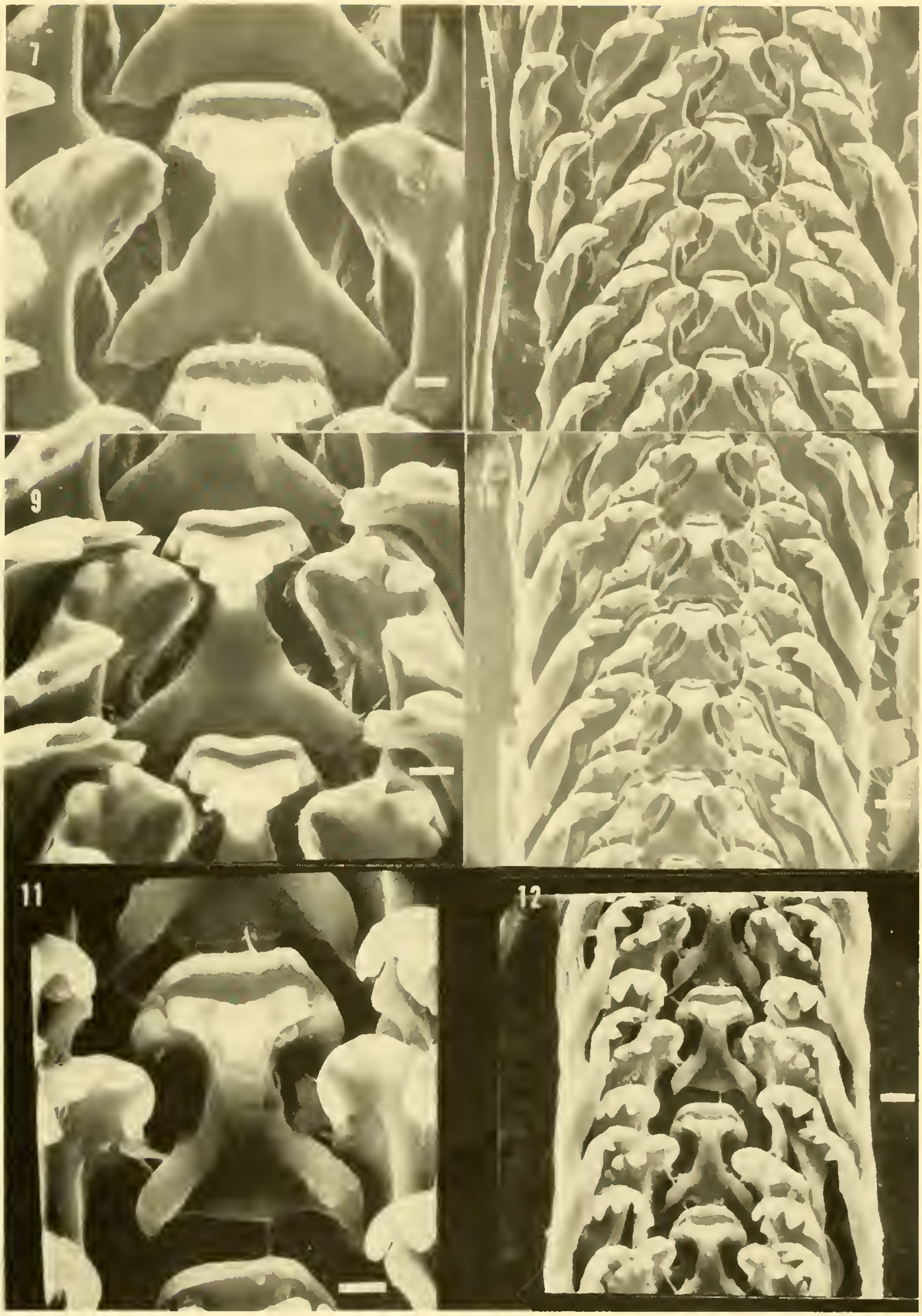
stage. It is not known how *L. scabra aberrans* reproduces. The considerable morphological variation present within both *L. scabra scabra* and *L. scabra angulifera* probably accounts for the large number of synonyms each has accumulated during its nomenclatorial history (see Bequaert, 1943, p. 23 and Rosewater, 1970, pp. 459, 460). According to Gaines, et al. (1974) there is much genetic variation in the subspecies *angulifera*. He attributes this in part to its ecology and life history and it may account for the observed morphological variation as well. In spite of these individual differences I consider the Indo-Pacific and the Atlantic subspecies to be extremely closely related.

It is somewhat surprising to me, therefore, to read in the detailed and interesting paper by Gallagher and Reid (1979) that they had decided to consider *L. angulifera* not to be a subspecies of *L. scabra!* Their main reason for this change was because Bandel (1974) stated that radular differences between the two indicated specific separation. Their decision to accord them full species status also was strengthened because Abbott (1974) did so and because they were so designated in most of the literature (although see Rosewater's 9 references cited herein). On checking Bandel's precise reasons for the separation I found that they were based on a comparison of his Scanning Electron Microscope examination of the radula of *L. scabra angulifera* (his Figs. 30, 31) with my line drawing of the radula of *L. scabra scabra* (Rosewater, 1970, Fig. 353). I feel that such a comparison may have yielded an erroneous impression because of deficiencies in my drawing which was based on the examination of a radula preparation of *L. scabra scabra* with an ordinary light microscope. Therefore, I have subjected radulae from specimens of all 3 subspecies to examination with the S.E.M. (see Figs. 7–12).

Bandel commented, "The denticles bordering the central cusps of the rachidian tooth of *L. angulifera* are absent in *L. scabra*." Although not detailed in my line drawing, they are indeed present as shown in Figs. 7 and 8. Bandel further remarked, "The frontal plate of the central tooth is straight in *L. scabra* and curved in *L. angulifera*." This difference would appear to be present in a comparison of my S.E.M. photos of the rachidian teeth (Figs. 7 and 9), but in the upper portion of my illustrations of several rows in the radula ribbons (Figs. 8 and 10) the differences appear to be attributable to orientation of the teeth rather than actual differences in their structure. I believe other differences pointed out by Bandel in the lateral and marginal teeth of the two subspecies may be due to difficulties in comparing his S.E.M. photos with my drawings, and also may possibly be due to some degree of variability between individuals of the same and different subspecies. It is unfortunate that Bandel (1974) based his decision on the radula alone, as these subspecies are so similar in a number of other characteristics.

Included for comparison with the other two subspecies are S.E.M. photos of the radula of *L. scabra aberrans* (Figs. 11, 12). From these illustrations it will be noted that the radula of this subspecies is similar in many details to the other subspecies. It is, however, usually of a smaller size (both shell and radula – see magnifications). I consider it to have developed more differences, due to isolation, from *L. scabra scabra* and *L. scabra angulifera*, than the latter have from each other.

The modern systematist has an admirable repertoire of sophisticated devices with which to classify taxa and these are nowhere better detailed than in the recent volume edited by Fretter and Peake (1978). In all likelihood some of these techniques could prove useful in furthering arguments concerning the subspecies of *L. scabra*, although *Davis (in* Fretter and Peake *ibid.*, pp. 117–118, 133, 152) stressed that these techniques are sometimes controversial at the infraspecific level. Mayr (1969) emphasized that . . . "No nonarbitrary criterion is available to define the category subspecies". The main attributes he mentioned are that the individuals forming a subspecies group be *phenotypically similar*, that they *inhabit a geographic subdivision* of the range of the species of which they are a part, and that they *differ taxonomically* from other populations of the species. Since the three entities I have assigned to the *L. scabra* group appear to me to satisfy these criteria, I suggest that they continue to be considered subspecies.



FIGS. 7–12. *Scanning electron micrographs of radulae of* Littorina scabra *subspecies.* **7** *and* **8**, Littorina scabra scabra, *female from Madras, India (USNM 701964).* **7**, *rachidian; bar = 10 μm, 700×.* **8**, *several transverse rows; bar = 50 μm, 200×.* **9** *and* **10**, Littorina scabra angulifera, *female from Isle of Capri, Collier Co., Florida (USNM 637271).* **9**, *rachidian; bar = 10μm, 900×.* **10**, *several transverse rows, bar = 25μm, 300×.* **11** *and* **12**, Littorina scabra aberrans, *female from San José Island, Pearl Islands, Panama (USNM 588870).* **11**, *rachidian; bar = 5μm, 2000×.* **12**, *several transverse rows; bar = 10μm, 750×.*

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CRAB PREDATION ON TWO SMALL MARINE GASTROPODS (CERITHIACEA)

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ABSTRACT

The frequencies of repaired crab-induced injuries were compared between littoral populations of Batillaria minima *and* Cerithium lutosum. *Habitat differences rather than shell morphology appear to be responsible for the large differences observed. Small, abundant gastropods may prove to be a previously unrecognized useful tool in analyses of predation.*

Crab predation on living bivalves of a wide size range, and on gastropods longer than a few centimeters has been convincingly demonstrated in the literature. (See, as examples: Landers, 1954; Menzel and Hopkins, 1955; Menzel and Nichy, 1958; Powell and Gunter, 1968; Hamilton, 1976; Menzel et al., 1976; Vermeij, 1976, 1977, 1979; Vermeij et al., 1980; Dudley, 1980.) To the knowledge of this author, however, no analysis has been done of crab predation on the small, abundant and ubiquitous gastropod species found on virtually all soft-bottom coastlines. This paper reports on two such snails from Florida.

MATERIALS AND METHODS

Collections of *Batillaria minima* (Gmelin, 1791) were made in March, 1979, at Matheson Hammock, Coral Gables, Florida. In March, 1980, collections of *Cerithium lutosum* Menke, 1828, were made at Frank Key in Florida Bay offshore from Flamingo. Both species are locally extremely abundant; the *Batillaria* were living in dense clusters on the sandy substrate of a widely exposed tidal flat, and the *Cerithium* were similarly clustered on the mud substrate between the roots of the mangrove *(Rhizophora mangle* L.) fringing the key. Each shell was measured to the nearest .01 mm with Vernier calipers, and the samples were divided into size classes. The presence or absence of repaired injuries was scored for each shell with the aid of a dissecting microscope. All injuries were of the kind that occur when a predator attacks a snail by chipping back the outer lip until either it is successful in capturing the snail or abandons the attempt. An unsuccessful attack is recorded as a healed injury (analogous to a jagged scar on human skin) that runs the entire length of the whorl on more or less the same plane as the lip of the shell. This type of lip-peeling injury is most typically induced by a number of brachyuran crabs (see Vermeij, 1978 for a review) which can manipulate their prey and direct attention to the lip. Arcsin transformations were performed on the data for the Chi-Square tests comparing repairs within size classes between species.

RESULTS AND DISCUSSION

Table 1 shows repair frequencies within size classes for the two species. It is immediately evident that all size classes of *Cerithium lutosum* have a much higher frequency of repair per shell than do those of *Batillaria minima.* For the two size classes that can be compared directly, 5–10 mm and 10–15 mm, p is <.005 (Chi-Square test) in both cases.

Table 2 tabulates the number of repairs per shell for each species, without regard to size classes, and again the contrast is striking. Most *B. minima* (85%) in the sample have never been attacked at all, and of those that have been attacked only 8% received more than one injury.

TABLE 1. *Repair frequencies within size classes of the two gastropod species.*

Species	*N*	*No. of Repairs*	*Repairs/ Shell*
Batillaria minima			
0 - 5 mm	278	35	.13
5 - 10 mm	1715	320	.19
10 - 15 mm	217	32	.15
Totals	2210	387	.18
Cerithium lutosum			
5 - 10 mm	91	59	.65
10 - 15 mm	181	209	1.15
15 - 20 mm	10	17	1.70
Totals	282	285	1.00

TABLE 2. *Number of repairs per shell for each species.*

Species	*N*	*No. of Repairs*	*% of Sample*
Batillaria minima	1869	0	85
	314	1	14
	18	2	.8
	5	3	.2
	4	5	.2
Cerithium lutosum	92	0	32.6
	117	1	41.0
	49	2	17.5
	19	3	7.0
	3	4	1.0
	1	5	.3
	1	6	.3

By contrast, 67.4% of the *C. lutosum* sustained injury; of these 39% received more than one.

When such differences in repaired injuries between species are observed two plausible reasons come to mind: 1) there are differences in shell morphology that confer differential protection against similar predation pressures, and 2) there are differences in the intensity of the predation pressure itself. It seems clear that the first reason has no relevance in this particular study. *Batillaria minima* and *Cerithium lutosum* are so similar morphologically (even though in different families) that Abbott (1974) makes a special point of cautioning against confusing the two.

The second reason, however, seems relevant: the predation intensity on this sample of *C. lutosum* was greater than that on *B. minima.*

Florida waters in general are well known to sustain large numbers of brachyuran predators (Menzel et al., 1976; Kent, pers. comm.), including *Menippe mercenaria* (Say) and numerous other xanthid species, plus portunids, such as *Callinectes sapidus* Rathbun. However, the exposed tidal flats of Matheson Hammock may well offer little or no protection to the juveniles of these probable unsuccessful predators of the small snails. As the tide advances and recedes the entire flat is systematically worked over by numerous species of wading birds searching for any edible prey. By contrast, the arching mangrove roots around Frank Key offer numerous refuges from avian predators. Similarly, though I made no direct observations, it seems likely that fish predators would have greater access to small crabs on the tidal flats than among the mangrove roots.

In passing, let me note that these predators could, of course, also attack small snails. However, such attacks would not result in the type of injury under consideration in this paper. Bird predators would be likely to swallow snails whole, leaving no evidence of their attack; fish predators would either swallow the snail whole, or crush it completely.

In addition to the probable greater protection afforded brachyuran predators around Frank Key, which permits the presence of greater numbers of lip-peeling predators, is another factor to consider. Florida Bay, a remarkably shallow expanse of water, is in all probability considerably warmer during the winter months than is the Atlantic-facing Matheson Hammock. Predators in the Florida Bay may well be more active in the cooler seasons; that is, they may have more time in which to inflict injuries on their prey.

In my opinion habitat differences like the two discussed here ultimately account for the differences in repair between these two snail species by affecting both the numbers and the feeding intensity of juvenile crab predators.

This study demonstrates that small snail species suffer unsuccessful predation by crabs to a far greater degree than many researchers have previously suspected. Consequently, they can be used to compare predation between populations and/or between habitats. Because these locally abundant species are so readily available they have considerable potential as a research tool.

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EXTENSIVE FLORIDA *LIGUUS* COLLECTION AVAILABLE

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RECENT DEATH

We regret to announce the death of Dr. Henryk B. Stenzel, paleontologist and oyster taxonomist, on September 5, 1980, at the age of 80. An obituary will appear in a forthcoming issue.

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An excellent reprint of The Nautilus is available from volumes 1 through 40 (with an index to vols. 1-34) unbound ($494.00) or bound in green buchram hardback ($578.00). Volumes 41 through 72 are not available, except occasionally as second-hand copies, usually, when available, at $20 each. Volumes 73 to date (vol. 94 in 1980) are $10 each. If 10 or more volumes are purchased between vols. 73 and 94, there is a 25% discount. Individual numbers (4 in each volume) are available only to those institutions attempting to replace lost or stolen numbers.

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National Museum of Natural History
Smithsonian Institution

The Department of Invertebrate Zoology anticipates a tenure-track opening on the scientific staff for a freshwater or terrestrial malacologist to function as an associate curator-researcher at the GS-11 level ($20,611) beginning February 1, 1981. We are particularly interested in all candidates with a Ph.D. and strong backgrounds in current systematic biology, molluscan anatomy and evolutionary biology. Send curriculum vitae, copies of publications, and statement of long-term research goals to Dr. Richard S. Houbrick, Search Committee, Department of Invertebrate Zoology, National Museum of Natural History, Smithsonian Institution, Washington, D.C. 20560.

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CONTRIBUTORS

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An *abstract* should accompany each paper.

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Several museums of natural history have extensive modern facilities and equipment for the housing and curating of voucher specimens. Material should be accompanied by the identification, locality data and its bibliographic reference. There is no charge for this permanent curating service, and catalog numbers, if desired, will be sent to authors prior to publication.